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components & systems **DESIGN**

JANUARY 1960

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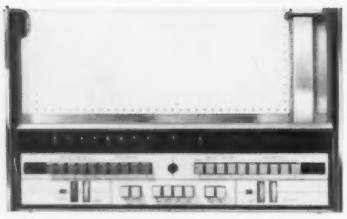
audio

amplifiers

James FLORA



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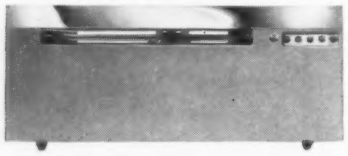

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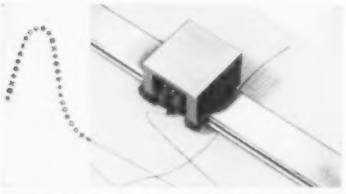

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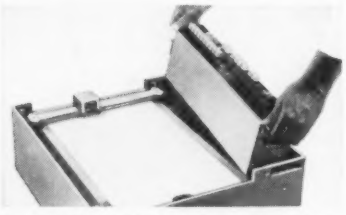

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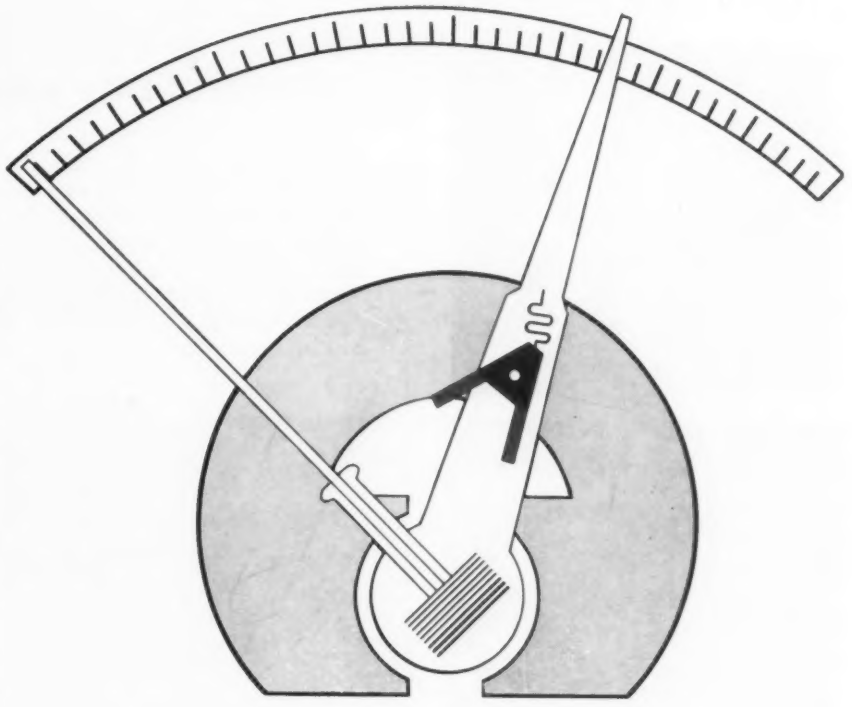

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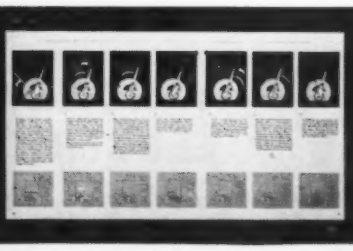

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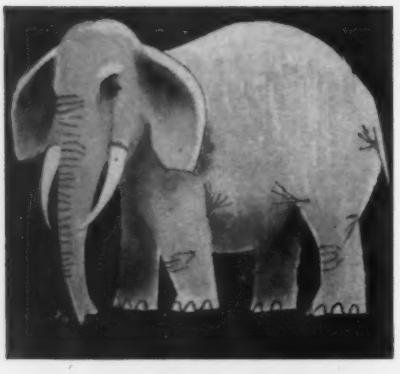

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COMPONENTS DIGEST SCHEDULE FOR 1960

Many readers interested in contributing information to our Components Digests have asked for a schedule of topics to be covered in 1960. Here is a tentative schedule based on a survey of reader interest. Also included, but not scheduled, will be supplementary information on Components Digest topics covered in 1959, to bring them up to date. The general purpose of these Digests is to organize information on well defined clas es of components and subsystems to give electromechanical engineers state-of-the-art knowledge on equipment they will be specifying.

Jan.	Audio Amplifiers I & II, Transistor Amplifiers
Feb.	Resolvers & Sine-Cosine Pots
March	Clutches
Apr.	Audio Amplifiers III, Magamps
May	Materials II, Insulations
June	EM Systems Packaging
July	Infrared and Photodetectors
Aug.	Hydraulic Components I, Servo Valves
Sept.	Read-Out Devices
Oct.	Small Analog Computers
Nov.	Gyros & Accelerometers
Dec.	Relays

Components Digest XI "Audio Amplifiers" introduces Martin Glasberg, Contributing Editor on our Staff. In this Digest, Martin will give electromechanical engineers information they need for evaluating and selecting packaged audio amplifiers. Parts I and II in this issue cover principles of operation of the various types of audio amplifiers and a detailed discussion of transistorized units. Part III, scheduled for the April issue, will include magnetic amplifiers and a summary of manufacturers' data on audio amplifiers in general.

Martin is a Project Engineer at the Research Division of the United Shoe Machinery Corp., in Beverly, Mass., engaged in the automation of shoe machinery and similar servo problems. He has worked on dynamic analysis for United Shoe's Atomic Power Dept., data processing for the Kimball Co., a United Shoe Subsidiary, and has been responsible for developing an extremely accurate programmer for the PLATO Electronic Beam Scanning System. He has also worked on fire control problems at the MIT Instrumentation Laboratory and the Weapons Guidance Laboratory at WPAFB. He received a Bachelor of Science and Master of Science Degree at Massachusetts Institute of Technology. Martin's point of view in reporting will be to present ideas on a practical level emphasizing physical rather than abstract reasoning. With this approach he proposes to apply modern mathematical tools in digestible form to give the reader a clearer understanding of the operating principles of the equipment reported.

Robert B. Brotherston

EDITOR

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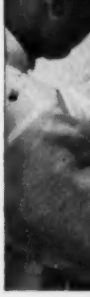

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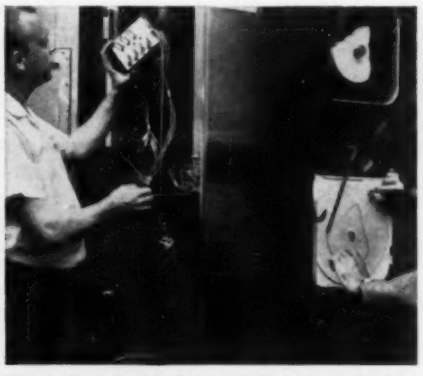

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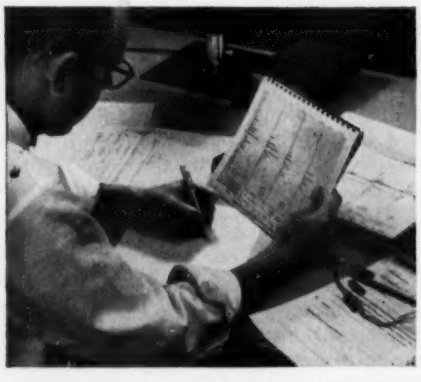

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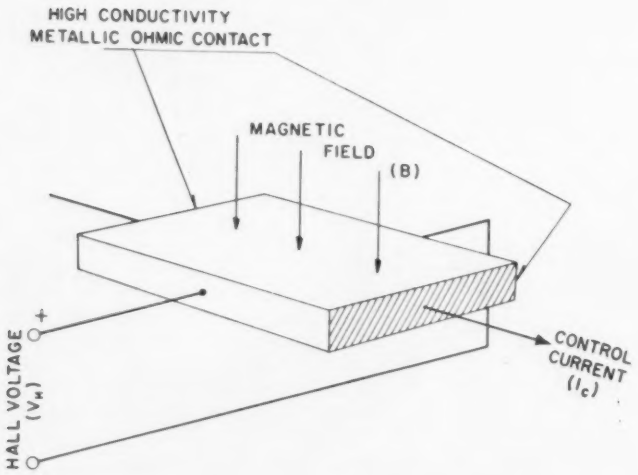

Fig. 1 To put the Hall effect to work, Westinghouse developed a Hall Generator, which consists of a thin wafer of InAs and is essentially a solid state multiplying element that provides an output voltage proportional to the product of the current passing through it and the field perpendicular to it. It is possible to have an output from the Hall generator with only control current applied. This output, called the null voltage, is due to the fabrication difficulties encountered in connecting the Hall output leads to the generator. The magnitude of this null voltage depends upon the magnitude of the control current and how closely the output leads are connected to equipotential points on opposite sides of the generator wafer. The fact that the characteristic curves of Figure 2 do not pass through the origin illustrates the effect of the null voltage. It is also possible to have an output from the Hall generator with only a field applied, if this field is varying. This voltage may be induced in the output by flux linking the output leads. It can be minimized, however, by making the plane of the loop, formed by the output leads, parallel to the field, as illustrated above.

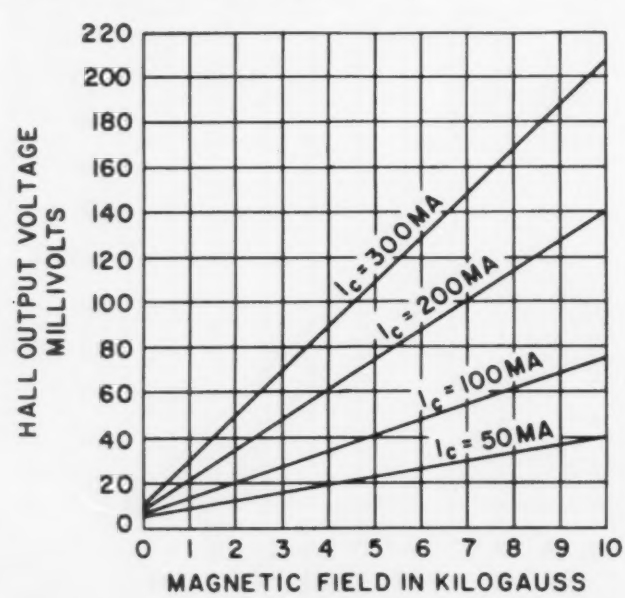

Fig. 2 Hall output (V_H) vs. flux density (b) for constant control currents (I_c). Note that the above relationship does not deviate in linearity by more than 0.5%.

APPLICATIONS OF THE HALL EFFECT

Watt Measurement With A Hall Multiplier

A physicist, E. H. Hall, discovered in 1879 that when a conductor through which a current is flowing is placed in a magnetic field, a potential difference is generated between the two opposed edges of the conductor in a direction mutually perpendicular to both the field and the current. Due to the small magnitude of this potential, the Hall effect has for many years been merely of academic interest. Development of very high mobility semi-conductor compounds, such as indium-arsenide (InAs) and indium-antimonide (InSb) which produce a useful Hall potential, has made possible practical applications of this phenomenon.

One such application is a portable instrument that can measure the intensity of a magnetic field and the distribution of the field in an air gap. The development of this device, manufactured by Messrs. Siemens and Halske, Erlangen, Germany, is described in **"Magnetfeld-Messgerat Mit Hall-Sonde"** published in **Elektrotechnische Zeitschrift-B,** 1958, No. 7. *Another application is a watt transducer, whose basic element is a semiconductor Hall multiplier.*

The basic problem of watt measurement involves finding a device or combination of circuit elements that will produce an output proportional to the product of two inputs. In the past, three basic multiplying devices have been employed to measure watts: the electrodynamometer mechanism; the induction-disc mechanism; and the thermal-converter circuit. The electrodynamometer and induction-disc use electromechanical elements while the thermal-converter makes use of static circuit elements. The principles and design considerations in the development of a Hall multiplier that will serve as a watt-measuring device were presented in a paper by Mr. T. Barabutes and Mr. W. J. Schmidt of Westinghouse Electric, East Pittsburgh, Pa., at an AIEE conference last spring. Westinghouse now announces the watt meters are in production.

HALL GENERATOR

The principles of the Hall generator are described in Fig. 1. The multiplying characteristics of the generator are shown by the equation:

$$V_H = R\, I_c\, b \times 10^{-8}/d \qquad (1)$$

where

V_H = instantaneous Hall voltage in volts.
R = Hall constant in ohm cm^3/coul.
I_c = instantaneous control current in amperes.
b = instantaneous flux density in gauss.
d = thickness of Hall generator in cm.

The Hall constant is dependent upon factors such as the mobility of the semi-conductor material and the length to width ratio of the semiconductor wafer. Fig 2 shows the relationship of the Hall constant to flux density. Equation (1) shows that the output voltage is inversely proportional to thickness. This is due to the fact that the internal resistance of the wafer is inversely proportional to the cross-

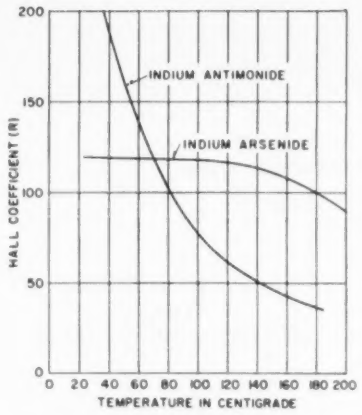

Fig. 3 Variation of Hall Constant with temperature for InAs and InSb. At normal ambient temperatures, the Hall constant for InSb is more than twice that for InAs, however, Westinghouse chose InAs because its rate of change with temperature is 0.02% per °C as against 1.3% per °C for InSb.

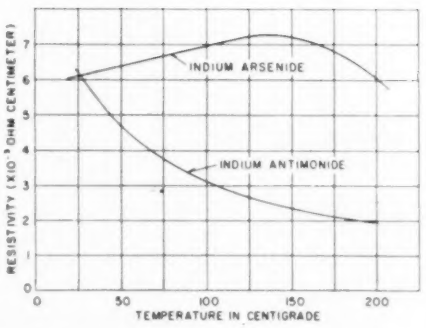

Fig. 4 Resistivity of InAs and InSb vs. temperature. Internal resistance may effect the external circuitry.

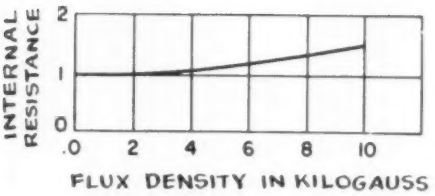

Fig. 5 Magnetoresistance effects in the Hall generator cause changes in the internal resistance in response to changes in the density of the applied field. The ratio of the resistance at a given flux density to the resistance at zero flux density vs. flux density is plotted above. At a flux density of 10,000 gauss, the internal resistance is approximately 50% greater than the value at zero fie'd. This variation is important because of its possible effect on the external circuitry.

sectional area. Analysis of these facts indicates the power output capabilities of the element is also inversely proportional to wafer thickness. However, the minimum thickness is limited by mechanical considerations. The two characteristics of the Hall element which are influenced by changes in temperature are the Hall constant and the resistivity of the semiconductor material. Curves showing the variations of these characteristics with temperature are illustrated in Figs. 3 and 4. Changes in the internal resistance due to changes in the applied field are plotted in Fig. 5.

THE HALL MULTIPLIER

Figure 6 illustrates the basic components of a Hall multiplier. The control current (I_c) is applied directly to the generator while the magnetic field in the air gap of a "C" shaped magnetic structure is produced by a current I_f. If the magnetic structure acts linearly, the flux density in the air gap will be given by

$$b = K_1 I_f \qquad (2)$$

where K_1 = constant of proportionality depending on the design of the magnetic structure

Substituting equation (2) in equation (1) yields

$$V_H = K_2 I_f I_c \qquad (3)$$

where $K_2 = K_1 (R \times 10^{-8}/d)$, a constant depending upon the parameters used in the design of the various elements.

The development of equation (3) shows that the device will produce an output voltage proportional to the product of two input currents. The maximum energy output obtained is determined by the maximum control current rating of the generator and the maximum flux density designed in the field structure. A 10,000 gauss field and a control current of 0.5 ampere will produce approximately 30 milliwatts of output power across a matched load. Methods of compensating for variations of the generator characteristics are discussed in Figs. 6 and 7.

HALL WATT TRANSDUCER

An ideal application for the Hall multiplier is the measurement of a-c power. Figure 8 shows how the multiplier is connected to perform this measurement. The field is energized by the current in the line, and the control circuit is energized by the line voltage. The resultant output from

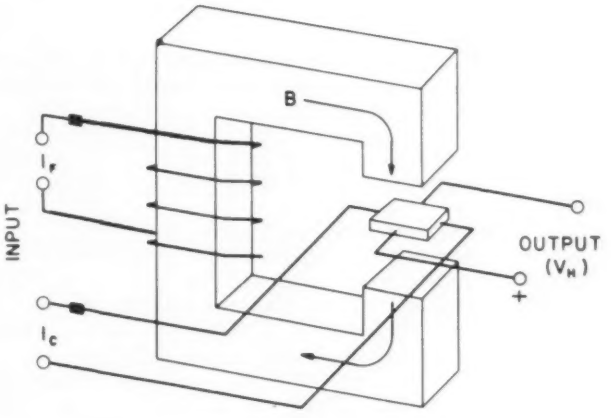

Fig. 6 Since the heart of the multiplier is the Hall generator, the problems imposed by the generator characteristics dictate the design of the device. An increase in ambient temperature decreases the Hall constant and increases the internal resistance of the generator. Both results tend to reduce the output voltage. If it is important to make the output of the multiplier independent of temperature, some form of temperature compensation is required. Since the device is a true multiplier, this compensation may be applied in any one of the three circuits. Compensation in the circuit producing the field might take the form of a temperature responsive magnetic shunt across the air gap. Addition of a thermistor circuit in series with either the control or output circuit will also provide effective compensation. Magnetoresistance effects may be minimized by making the external resistance in the output and control circuits as large as possible, and by operating the magnetic circuit at the lowest possible flux density consistent with the desired output. An induced voltage, due to a-c magnetic fields, may be nullified by a single turn coil arranged to link an adjustable amount of the field's leakage flux and connected in series opposition with the output leads. If only the d-c component of the output voltage is of interest this compensation would not be needed.

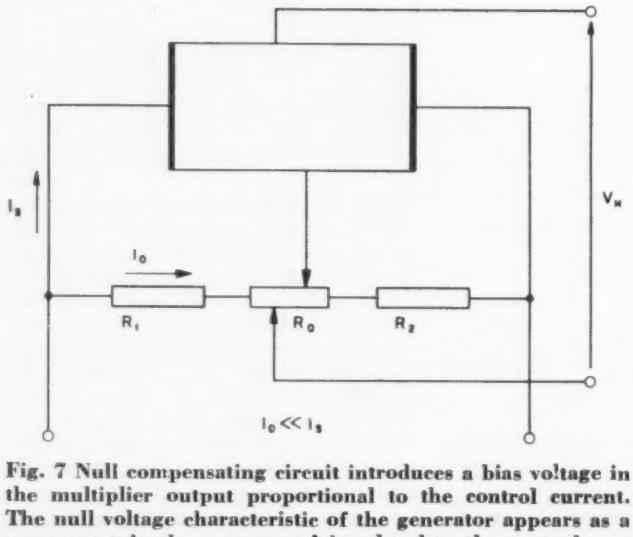

Fig. 7 Null compensating circuit introduces a bias voltage in the multiplier output proportional to the control current. The null voltage characteristic of the generator appears as a component in the output and is related to the control current only. Whether or not compensation is required will depend upon the application of the multiplier. No compensation is needed if the control current is an a-c quantity and only the d-c component of the output is of interest, or, if the control current is a d-c quantity and only the a-c component of the output is of interest.

the transducer is proportional to the power being delivered by the a-c circuit. The conditions may be expressed mathematically by the following equations:

$$I_f = K_3 I_L \quad (4)$$

$$I_c = K_4 e_L \quad (5)$$

where

I_L = instantaneous line current
e_L = instantaneous line voltage
K_3 & K_4 = constants of proportionality

Substitute equations (4) and (5) in equation (3)

$$V_H = K_2 K_3 K_4 I_L e_L \quad (6)$$

Assume that the line voltage and current are given by:

$$I_L = I_{max} \sin(\omega t + \theta) \quad (7)$$

$$e_L = E_{max} \sin \omega t \quad (8)$$

Substitute (7) and (8) in equation (6) and expand

$$V_H = K_2 K_3 K_4[(ImEm/2) \cos \theta - (ImEm/2) \cos(2\omega t + \theta)] \quad (9)$$

Since the frequency response of the Hall generator is in the order of one megacycle, the output will follow the instantaneous power wave which is expressed mathematically by equation (9). Inspection of this equation shows that the transducer output contains two components; a d-c term, $I_m E_m \cos \theta/2$ and an a-c term, $I_m E_m \cos(2\omega t + \theta)/2$. The d-c term is proportional to the true power in the a-c circuit and is, therefore, a measure of this power.

TRANSDUCER WATTMETER

Westinghouse Electric's self-contained polyphase wattmeter consists of a d-c instrument mechanism and a Hall watt transducer. The transducer develops a d-c voltage proportional to the watts represented by the current and voltage applied to the wattmeter terminals. This d-c voltage operates the d-c instrument. Figure 9 shows the Hall generator element and a view of the polyphase wattmeter with the case removed. In this design the magnetoresistance effects were minimized by making the control circuit and

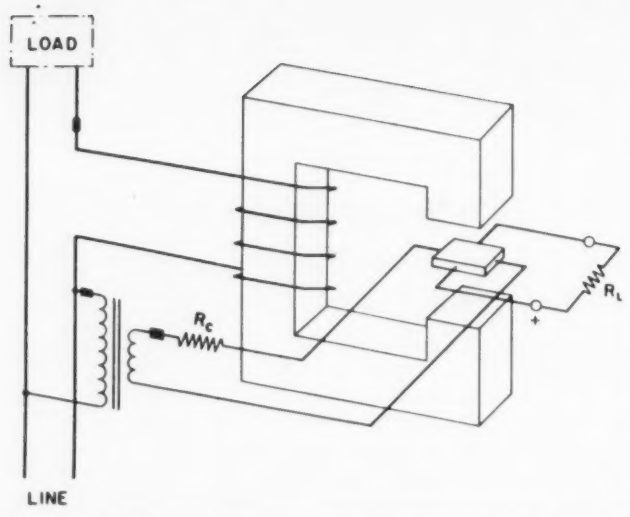

Fig. 8 Hallwatt transducer connected to measure single phase power. To extend its application to polyphase power measurements, two or more such devices may be used with their Hall outputs connected in series.

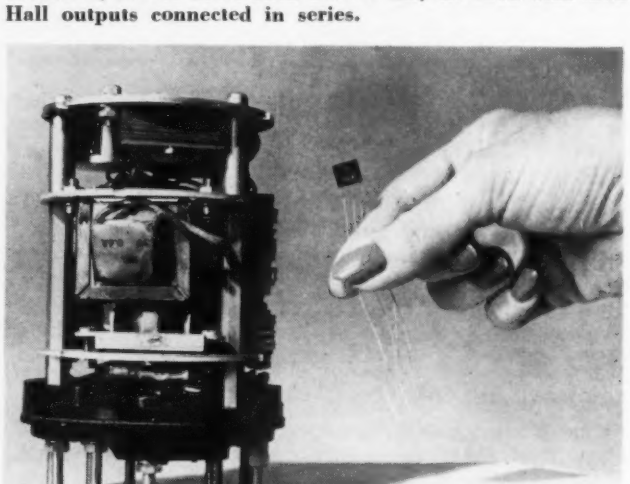

Fig. 9 Transducer wattmeter and Hall generator element.

output circuit resistances large with respect to the internal resistance of the generator, and by operating the magnetic circuit at low flux densities. Overall temperature compensation was achieved by adding a thermistor circuit in series with the transducer output. Since the input quantities are a-c, and a d-c instrument is used for indication, no compensation for the induced and null voltages was required. Similarly, the a-c component of the Hall output is averaged by the d-c instrument and therefore, does not effect the indication.

In addition to its inherent advantage of being truly static, the new watt-measuring device features small size, instantaneous response, low internal impedance and simplified circuitry.

Two versions of the watt transducer have been designed: the first produces an unfiltered d-c current output in the milliampere range; the second produces a filtered d-c millivolt output. The first version is used for driving direct-acting external instruments, or control windings of magnetic amplifiers, where there is no sensitivity to a-c ripple. The second is applied where control devices, telemetering transmitters, or potentiometric recorders must have a d-c signal relatively free of ripple. Both versions are made for single-phase, three-phase three-wire, and three-phase four-wire application.

Circle No. 77 on Inquiry Card

Squirrel Cage Motor Starters

600 volts maximum, three phase, across-the-line starters are designed to provide magnetic reversing and full voltage starting of squirrel cage motors. Starters consist of two mechanically interlocked three-pole contactors each with normally open control circuit interlock. One model includes two thermal overload relays for removing the motor from the line in the event of an unsafe overload. Clark Controller Co., Cleveland, Ohio.

Circle No. 132 on Inquiry Card

Miniature Analog Computer

Weighing just 23 pounds, a 10 amplifier full-fledged analog computer is said to be the smallest ever made. The computer solves up to seventh order differential equations or ninth degree Leplace transforms. For solving more complex problems, up to three computers can be slaved together for 10, 20, or 30 amplifier operation.

Besides the 10 amplifier channels, a complete computer includes a null voltmeter, five pots for coefficients or initial conditions, all the necessary power supplies and control circuitry. Measuring only 5¼ inches high, 19 inches wide, and 10¼ inches deep, the computer can be conveniently operated on desk tops and with removal of a few screws, the problem board tilts up for rack mounting.

Extremely flexible, the computer, by patching at the problem board, can be converted to a power supply, low frequency signal generator, voltmeter, and a tester of vacuum tubes, diodes and transistor characteristics. Donner Scientific Co., Concord, California.

Circle No. 203 on Inquiry Card.

High Temperature Transistorized Servo Amplifiers

Three new models of 400 cps servo amplifiers with power output capabilities of 3.5, 6.2 and 9.3 watts at 40 volts rms feature all silicon transistors for high temperature reliability. An outstanding characteristic is that without any type of heat sink mounting they are capable of delivering rated power continuously in an ambient temperature of −55C to +100C. They are designed to drive any standard size servo motor with a 40 volt center tapped control winding. Other design features are: stabilized stages to prevent thermal runaway, internal negative feedback to insure minimum a-c gain variation ,and a negative overall feedback connection to adjust gain to a desired level. All units operate from a 28 volt d-c power supply, have a 10,000 ohm input impedance, and are fully potted and hermetically sealed. Magnetico, Inc., T. A. Div., East Northport, N. Y.

Circle No. 133 on Inquiry Card

1000°F Aluminum Wire

Newly developed 1000°F boron-free aluminum wire is ideally suited for high temperature and nuclear radiation environments. The wire is insulated with boron-free ceramic, tradenamed "Durock". Important characteristics: cross section capture—less than 18 barns; porosity—moisture resistant after 3 hours at 1000°F, non-hygroscopic; tensile strength—in excess of the bare conductor; low temperature—operating at cryogenic levels; migration—none between conductor and ceramic; thermal shock—impervious to 800°F instant thermal air shocks; wire sizes—4 to 100 mills. Technical Industries Corp., Pasadena, Cal.

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HIGH TEMPERATURE PNEUMATIC ACTUATORS

Application of Nutating Disc Motor to A 1200°F Design

Ability of pneumatic actuation systems to operate at extremes of temperature make them attractive for many applications. Techniques for system stability and methods of coping with low bulk modulus have been established. Actuation by means of various types of pneumatic motors at elevated temperature has been demonstrated. In particular, the nutating disc type positive displacement pneumatic motor is applicable to high temperature environments and high response requirements.

These were the summary remarks of W. J. Koerner, Project Engineer of the Marquardt Corp. in a paper on "High Temperature Pneumatic Actuators", presented at the October SAE National Aeronautic Meeting in Los Angeles, Cal. Mr. Koerner confined his discussion to the direct type of pneumatic systems, which use available energy from ram air or compressor bleed air and multiply this by motor and mechanical means at the actuator to the force level required.

Discussing some advantages of pneumatics at high temperatures, he pointed out that an elemental gas, such as air, is thermally stable throughout the entire working temperature range. Lubricity and bulk modulus remain essentially constant. At elevated temperatures, air has higher viscosity than most hydraulic fluids (see Fig. 1). The narrow viscosity range of air over a wide temperature range is important, Koerner said, because the more constant fluid metering reduces variations in control characteristics with changes in temperature. He attributed the present promising position of pneumatics primarily to three important contributions:

- Advanced system stability techniques and methods of overcoming the low bulk modulus (high compressibility) of this media.
- Advent of efficient positive displacement air motors capable of sustained operation at high temperatures.
- Important recent advances in the development of high temperature materials.

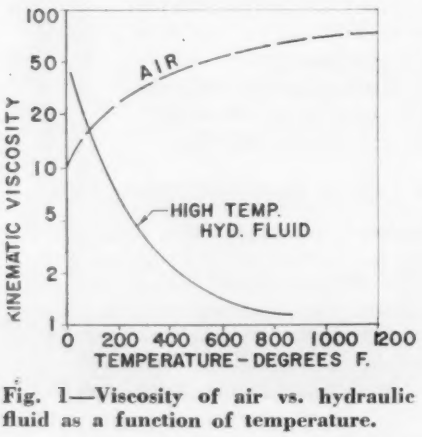

Fig. 1—Viscosity of air vs. hydraulic fluid as a function of temperature.

TYPE OF MOTOR / PARAMETER	EFFICIENT OPERATION AT LOW R.P.M.	HIGH STALL TORQUE	HIGH VOLUMETRIC EFFICIENCY	LOW INERTIA BUILD-UP	SIMPLICITY (VALVING, ETC.)	CONSTANT TORQUE OUTPUT
NUTATING DISC	G	G	G	G	G	G
CAM - PISTON	G	G	G	F	P	F
VANE	F	F	P	G	F	F
LOBULAR	P	F	F	P	F	F
GEAR	P	P	P	P	G	F

G-GOOD
F-FAIR
P-POOR

Fig. 3—High temperature pneumatic air motors

STABILIZATION TECHNIQUES

Proven stabilization techniques, Koerner said, are now being used in highly reliable pneumatic actuation systems. One of the most important of these, he said, was developed by J. L. Shearer of M.I.T. It uses plenum chambers or additional volumes of air isolated from the servo actuator piston or air motor chamber by restrictors. A typical configuration is shown in Fig. 2. These chambers smooth the response and improve system stability by absorbing high frequency oscillations. Sizing of the restrictors, as well as the plenum chamber volume, is determined by "tuning" the loop to obtain the desired damping with the loads, masses, spring constants, volumes and dimensions fixed. This restrictor-chamber combination is called a "transient flow stabilizer" since pressure drop occurs across the restrictor only during transients.

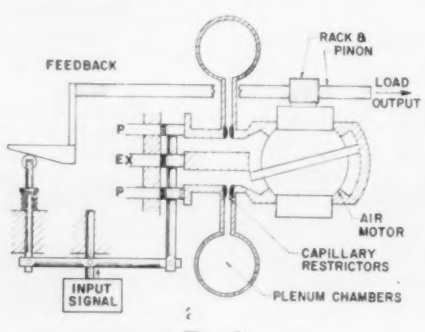

Fig. 2

POSITIVE DISPLACEMENT AIR MOTOR

Results of an early evaluation by the Marquardt Corp. of several types of air motors considered for high temperature use are summarized in Fig. 3. As indicated by this table, an air motor based on the principle of the nutating disc appears promising for use in a high temperature pneumatic actuation system. Absence of complex valving in this type of motor assures high reliability, Koerner said.

To describe the nutating disc principle he showed how it is exemplified in the common domestic water flow meter. The movable element in this type of motor is a flat disc attached to a central sphere and mounted in an annular chamber which has a spherical sidewall bounded by conical upper and lower surfaces. The plate is prevented from rotating about its own axis such that when subjected to a differential pressure, a nutating motion is executed. Rotary power is obtained by means of a "Z" crank.

In this type of non-expansion positive displacement motor, output torque is a direct function of the volumetric displacement and differential pressure across the disc. The air weight flow increases at essentially a constant rate with speed and is directly proportional to the differential pressure.

Koerner summarized the qualities of the nutating disc motor as follows:

- High performance and high effi-

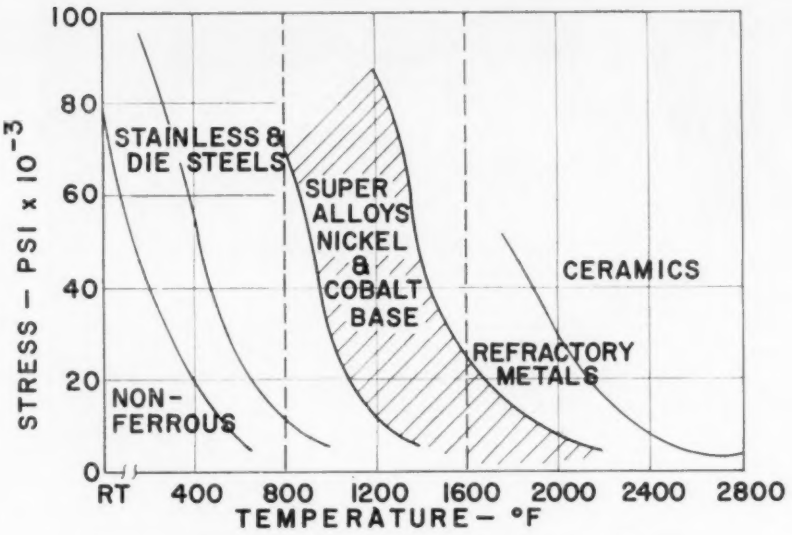

Fig. 4—Material usability range 1000 hr. rupture stress

ciency throughout a wide range of inlet pressures, temperatures, speeds and loads.

- Rapid reversing operation and high frequency response capability.
- Less air consumption in stall or brake condition.
- Rotational speed compatible with driven device.
- High stall torque.

MATERIALS

Koerner listed several necessary considerations to be taken into account in selecting materials for long duration hot gas actuation systems.

- System loads, their method and rate of application and their variations with temperature.
- Strength to weight ratio at operating temperatures with special consideration for creep, deflection, package size, etc.
- Compatibility with environment. For example, oxidation, nuclear radiation, etc.
- Friction and wear characteristics.
- Coefficients of thermal expansion.
- Thermal conductivity and emissivity.
- Ease of fabrication.

Referring to Fig. 4 showing material usability versus temperature range based on 1000 hour rupture stress, he pointed out that cobalt base and other super alloy metals are of primary importance for design at temperatures around 1200F. But, he warned the conventional "super alloy" list for high temperature service must be considerably abbreviated for actuator design. He reported that Marquardt is presently using the following alloys successfully in applications for continuous operation with 1200F gas temperatures: A286, S816, Haynes Stellite #3, #16, #19, 6B and #25 Alloy, M252, J1570, Udimet 500 and Titanium Carbide.

While basic stress rupture data such as presented in Fig. 4 are available to the designer, dynamic data are lacking, Koerner said; literature surveys in the field of high temperature wear and friction properties reveal a definite lack of data applicable to the wear problems in high temperature, non-lubricated machine design. The most desperate need and that which is presently limiting the growth of high temperature pneumatic actuation systems, he said, is high temperature wear and friction data. A comprehensive basic research program is needed, he said, to determine as closely as possible the mechanism of wear and optimum material combinations.

ACTUATOR DEVELOPMENT

An air motor actuator presently under development at Marquardt for use in a 1200F direct ram air system is shown in Fig. 5. Its general characteristics are adaptable for flight control or other airborne actuation requirements. The prime mover is an opposed pair of nutating disc motors operating 180° out of phase. Mechanical ratio is such that for each inch of actuator rack travel, the motors rotate five revolutions.

Materials were chosen for nearly equal thermal expansion coefficients, adequate oxidation resistance, strength, no unreasonable fabrication difficulties, and where applicable, adequate fatigue strength and hot hardness. The most serious lack of data during design, Koerner said, was that pertaining to rolling contact fatigue stresses and wear data for the anti-friction bearings and gears.

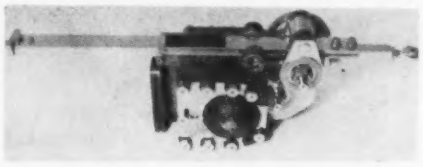

Fig. 5

Anti-Friction Bearings. A material with good hot hardness retention at 1200F was needed for the bearings. Hertz compressive stresses are in excess of 200,000 PSI for reasonable sized bearings. The best choice appeared to be one of the more specialized of the cobalt base materials. Data was not available on the surface fatigue properties of these alloys at 1200F, however. Available hot hardness data and room temperature properties directed the use of Haynes Stellite #3 for both the bearing races and rolling members, despite its slightly lower hardness at 1200F than that of some of its sister alloys.

Gears. High gear tooth loads and gear size limitations necessitate Hertz compressive stresses of 20,000 PSI and tooth bending stresses of 50,000 to 60,000 PSI. This required a material with good hot hardness retention but with greater ductility than Haynes #3, especially because of an imposed 10G vibrational load. The best available material was Haynes Stellite 6B, which is a wrought, cobalt-base material with compatible expansion characteristics. Available data indicated the high temperature wear resistance of 6B to be good.

Housing And Structure. The air motor housing, crank shaft, and most of the structural parts of the machine were made of alloy S-816. It is available in cast and wrought form, it has good strength properties at 1200F, its thermal expansion characteristics are compatible with the bearing material, Stellite #3, and it is machineable with newly established techniques.

Lubrication. No lubrication system was provided. At the time of design, Marquardt could find no proven lubrication tion method which would allow operating temperatures of 1200F. Recently, however, Koerner said, the possibility of beneficial lubricating properties of several solids and gases at temperatures above 1000F have been indicated.

Testing. The unit was tested in a hot box with 1200F environment and 1200F driving air. The rack was removed and steady state output torque at rated speed was reacted and measured through a dynomometer attached to the last gear stage shaft. It operated at this temperature for several hours at rated loads and speeds.

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PRINTED CIRCUIT ADVANCE

New Copper Paste For Screen Printing Circuits On Ceramic

A new method for producing printed wiring directly on ceramic bases without the use of adhesives has been developed by A. W. Treptow and Miss Lucille Finneran of Bell Telephone Labs. Basis of the new process, which uses standard silk screening techniques for forming the pattern, is a specially formulated copper-bearing paste. Following the printing of the desired pattern on the ceramic base, the piece is fired in a two-step process, resulting in a clean, durable pattern with excellent electrical characteristics.

In present methods of production, a sheet of copper foil is usually bonded to the ceramic or plastic base with an adhesive. The desired pattern is then produced by one of several methods usually involving the removal of undesired material. The bond of the copper to the base thus is dependent on the strength of the adhesive. Often, it fails during subsequent processing operations, such as soldering or assembly.

A. W. Treptow and Miss Lucille Finneran, Bell Te'ephone Labs, examine the screen printed pattern produced using a newly-developed copper paste for circuits printed directly on ceramic bases. The new method has the advantage that it requires no adhesive to bond the copper pattern to the ceramic. Bond strengths are over 2000 pounds per square inch, and do not fail under dip soldering conditions or during assembly operations. It should be competitive in cost with conventonal printed wiring techniques.

Good bonds can also be developed when fired silver or fired molybdenum is used on ceramic bases. Silver is more costly than copper, dissolves more quickly in molten solder and, under some conditions, is subject to migration and whisker growth. Molybdenum compositions are high in electrical resistivity and generally require electroplating to render them solderable and to improve the conductivity.

With the new process, a paste is prepared from a finely ground mixture of copper oxide and a special glass frit, blended with a standard silk screen printing vehicle. The

paste is used to print the pattern on the ceramic, and the "card" is heat-dried to remove solvents. After drying, the card with its pattern is fired in air at 750C for twenty minutes to burn off the printing vehicle. This operation leaves a non-conducting copper oxide pattern, ready to be reduced to metallic copper.

The second firing operation is conducted at 850C for thirty minutes, in a controlled atmosphere containing hydrogen, nitrogen, and oxygen. The hydrogen in the atmosphere reduces the copper oxides to metallic copper, while the oxygen prevents reduction of other oxides in the system and promotes good wetting of the glass frit and the ceramic. Without the oxygen present, a poor bond results.

Printed wiring cards prepared this way can be dip-soldered without bond failure, and without the use of corrosive fluxes. In tests of bond strengths, 20-gauge headed wires were attached to the pattern with an area contact about .01 square inch. Bond failure did not occur until about 2000 psi tensile pull, and even then generally involved breaking out the ceramic rather than bond failure.

With the oxygen in the controlled atmosphere, only about 5% glass frit is required in the paste to achieve good bonds. This small amount of inert material does not greatly affect the conductivity of the copper film. Resistivity of the film is in the order of 0.0015 ohms per square, which is well within requirements for typical printed wiring applications.

The composition of the controlled atmosphere may be forming gas (85% nitrogen and 15% hydrogen) with the addition of 0.4 to 4.5% oxygen. Such a gas mixture is non-flammable.

The process suitable for automatic production techniques should prove competitive with other printed wiring methods in cost.

There are other potential uses for the new copper paste in addition to printed circuits. With suitable modification of the vehicle, the copper can be applied with a brush or spray gun. When fired, these coatings form a good base for making metal to ceramic bonds, using lead-tin solders.

Compact Air Valves

A new series of direct solenoid operated air valves claimed to be the most versatile valves available include single and double-solenoid 4-way, 3-way, and 4-way 5-port types in ¼, ⅜ and ¾ in. sizes. All valves come complete with prewired bodies and bases. The valve body simply plugs into the base to complete the electrical connections. In addition to automatic operation, manual screwdriver or ball-type operators are standard on all solenoids. Valves also can be set to either "locked-in" or "locked-out" position with the conrtol. The manufacturer believes that this is the first time that such features normally considered "accessories" have been included in the basic valve design at the standard valve price.

All valves are equipped with new solenoids, which require no tools to assemble or disassemble and are interchangeable among all valves of the same port size. The solenoid assemblies are completely cushioned in rubber, have fully encapsulated sealed coils, and the solenoids give powerful action with remarkably low power consumption (0.80-amp inrush and .125 holding for the ¼-in. size). Fasteners have been eliminated in the solenoid assembly, greatly increasing reliability and life. The design also makes it impossible to assemble the solenoids incorrectly. Mechanical Air Controls, Inc., Detroit, Michigan.

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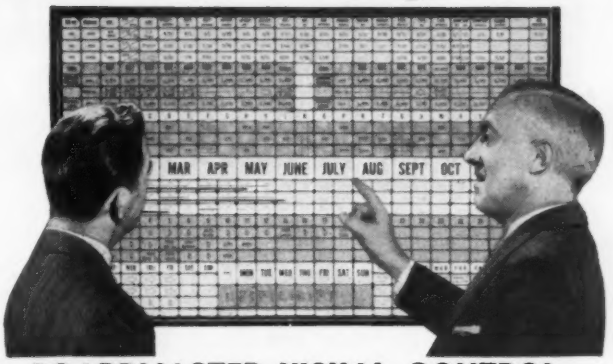

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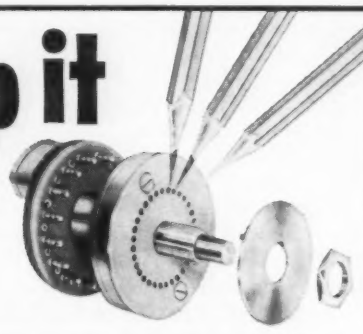

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MAGNETIC ANALOG STORAGE

New Method Permits Economical Digital-To-Voltage Conversion

In PCM telemetry or other digital data transmission systems, a digital-to-voltage conversion is required at the receiver or during the reading operation. A recent paper by Max Palevsky, George Slocomb and Donald Block of the Packard Bell Computer Corp., Los Angeles, Cal., discusses the problems involved when a large number of variables have to be converted and presents a method of voltage storage that permits construction of small, economical and reliable digital-to-voltage conversion systems.

With a few variables, digital decommutation is appropriate, together with a digital-to-analog converter for each variable. As the number of variables increases cost and component count become prohibitively high, requiring an alternate approach of a single digital-to-analog converter and an analog decommutator. As each variable is presented to the converter, the converter output is switched into the appropriate storage element. When any given variable is not being converted, its value is held in the analog store. If time-sharing is to be employed, then a method of switching and storing voltages is needed.

The most widely used analog switching technique employs a bridge of silicon diodes to successively gate relatively high-level voltages. This technique produces a voltage switch that is accurate, stable, and reliable but has one drawback in the present context, that of being current limited. In order to supply large currents, some form of transistor switch is required, and these in general lack the accuracy, stability, and simplicity of the diode scheme.

TRANSFLUXOR STORAGE

A new method of analog storage that promises to satisfy a number of requirements that are only imperfectly met by present methods uses the nondestructive readout properties of the Transfluxor. Once set, this magnetic device will retain its stored energy level to tolerances fixed primarily by temperature changes and power supply drift. During the storage period the transfluxor can supply power to drive external circuitry without any significant deterioration of the stored information. It is relatively unaffected by system power failures.

Fig. 1 (a) A ferrite core in a transfluxor configuration (b) when a large current is applied to the block winding, the flux pattern is oriented in the same direction for both leg 1 (area between large hole and small hole) and leg 2 (area outside of small hole).

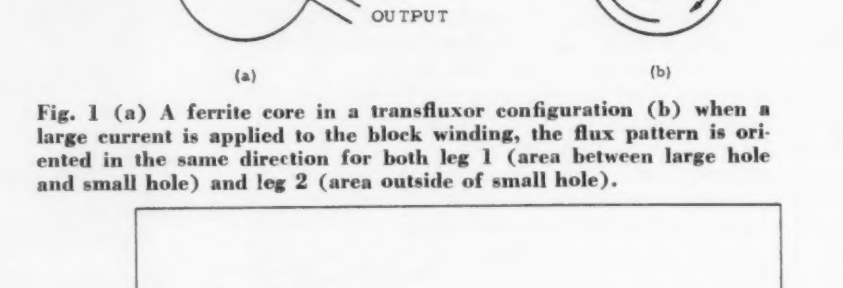

Fig. 2 Block diagram of a single transfluxor storage loop.

REVIEW OF TRANSFLUXOR OPERATION

First consider a ferrite core in a transfluxor configuration such as the one shown in Fig. 1a. If a large current is inserted into the block winding, the core will completely saturate in one direction, orienting the flux pattern as shown in Fig. 1b. A constant a–c drive is inserted across the excitation windings. When the drive is positive the current tries to increase the flux in leg 1 and decrease the flux in leg 2. Since leg 1 is saturated, no increase can occur so there will be no flux change. When the drive goes negative, the current tries to increase the flux in leg 2 and decrease the flux in leg 1. Since leg 2 is saturated, no increase can occur, so again there is no flux change. In this state there is only air coupling between the excitation and the output windings and the output will be small. One might ask why the a-c drive cannot reverse flux around the large hole since it is prevented from going around the small hole. Actually, it can. To prevent this, the excitation must be kept below a maximum limit.

$$i_{ex} < 2\pi H_L R/N$$

where R = radius of shortest possible flux path around the large hole.

N = number of turns.

H_L = magnetizing force required to switch the flux around any loop from one saturated state to the other.

If H is the magnetizing force produced by i_{ex}, for the cores to be useful, the maximum cross-hatched circle, in figure 1b, must have a smaller radius than the large hole. By controlling Ni_{ex} it is then possible to keep $H<H_L$ around the large hole while still providing a current capable of switching all the flux around the small hole.

Consider next a current inserted in the set winding great enough to switch flux around the large hole. This is the maximum flux which can be switched by a current in the set winding. Now when the drive goes negative the current tries to reverse the flux in both legs 1 and 2. Since the drive current has been adjusted so that $H > H_L$ in the cross-hatched area, the flux is switched. When the drive goes positive, the current is re–reversed back into legs 1 and 2. A large flux transfer around the small hole produces significant magnetic coupling between the excitation winding and the output winding, causing a large output.

STORING ANALOG INFORMATION

Thus far the technique operates as a digital storage, but does not provide for obtaining a defined analog voltage. To reach any level between the two end limits it is necessary to proceed a step further. Two methods are available to step the output voltage in equal increments over the full scale range,

current control and voltage control. Due to the fact that as the voltage is stepped in equal increments the radius of the switched flux ring changes, the use of current control would require a constantly changing current for each discrete step. Since this is difficult to implement and also requires dependence of the current on core characteristics, a voltage control has been used. The magnetic flux, which is switched, is the integral of the voltage. If a constant width and constant amplitude voltage pulse is used each pulse will provide the same volt-time area and will therefore switch an equal increment of flux.

With the transfluxor enclosed in a feedback loop and the system adjusted to provide a predetermined maximum volt-time area per pulse it is possible to control the maximum flux change per pulse. If, as the error is reduced, the voltage amplitude becomes proportional to error, it becomes possible to store analog information in the transfluxor. A means must also be provided to determine which winding must be pulsed. If the system over-corrects, the opposite winding will be pulsed, bringing the system back toward the correct value. Fig. 2 shows a simplified block diagram of a single transfluxor storage loop. The sections shown inside the dotted box can be time-shared. The d-c error is amplified and the polarity of the error is used to sense which of the two output lines should be pulsed. The amplitude of the pulses is proportional to the amplitude of the error voltage up to some pre-determined maximum. The outputs of the amplifier are pulse amplified and used to drive the control windings of the transfluxor core. The core is excited with a constant a-c current excitation and the amplitude of the a-c output is completely controlled by the setting of the core. The output is used to drive a detector which permits a d-c output from plus to minus to be obtained even though the core output never reaches zero. The output d-c is fed back and compared with the input. When both signals are equal the core is no longer pulsed and the gates can be opened. This effectively disconnects the control windings and allows permanent storage of the information in the core.

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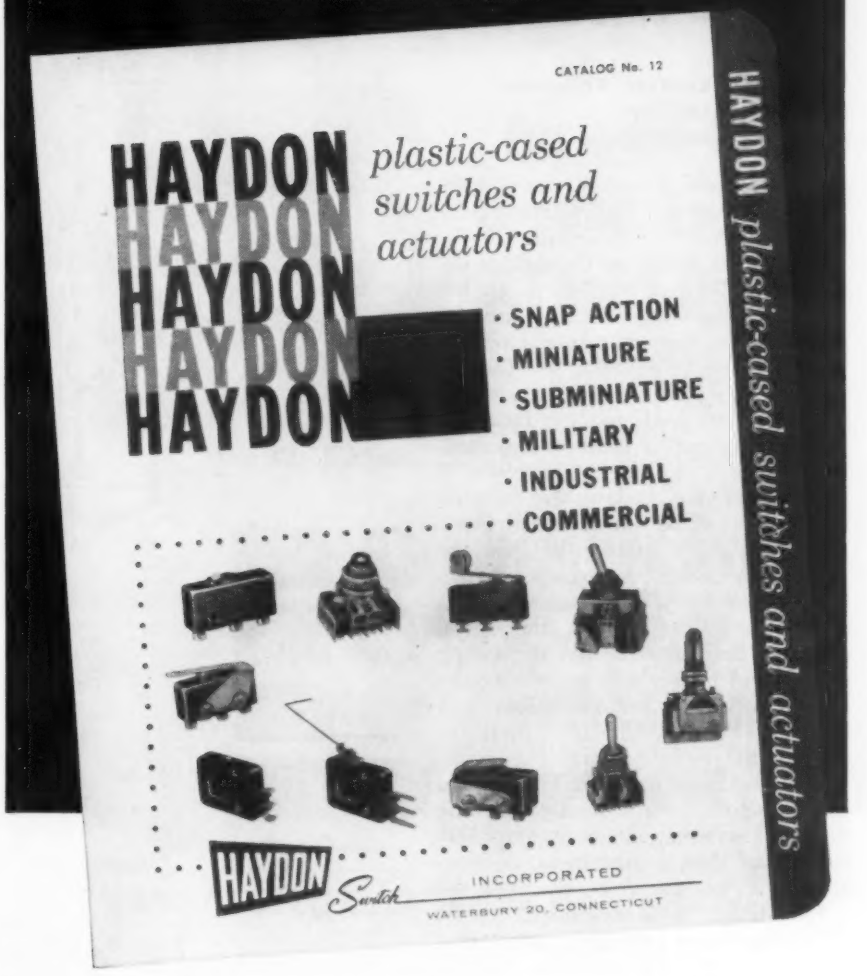

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CIRCLE NO. 29 ON INQUIRY CARD

IMPROVED MAGNETIC CORE DIGITAL CIRCUITRY

Transistor Emitter Follower Improves Stability And Increases Logical Gain

Continuing research on electronic computer circuitry and components at the National Bureau of Standards for the United States Air Force Cambridge Research Center has resulted in an improved digital magnetic amplifier. By modifying a magnetic core amplifier circuit developed earlier at the Bureau, E. W. Hogue has designed a new circuit with improved stability, increased logical gain, and a faster complementer.

Semiconductor diode gating, because of its economy, flexibility and dependability, is widely used to perform the logical functions of a high-speed electronic computer. To overcome the loss of signal power through the gates, amplifiers are inserted into the gating structure at intervals to regenerate the signal. Although vacuum tubes and transistors are commonly used to amplify the signal, saturable core reactors also show promise. The Bureau has therefore been investigating the use of these components as amplifiers because of their compactness, dependability and low power consumption.

Essentially, these amplifiers consist of diode-resistor networks associated with miniature saturable-core reactors driven by a "clock." The "clock" in this case is a 300 kc low-impedance sinewave source. An amplifier serves to transmit pulses, corresponding to binary "ones", or no pulses—zeros—depending on the input to the stage.

Figure 1 is the circuit diagram of a magnetic core amplifier with associated circuitry. Between the vertical dotted lines are two stages: the upper stage is an amplifier and the lower one is a complementer. Outside of the dotted lines are diode-resistor networks to provide the logical AND-OR gating. The stages can receive an input signal from the OR-gate.

Most of the power gain of the amplifier is provided by the saturable core reactors. Current from clock e'_c, together with the total current from R_o and all the resistors of the driven AND-gates in parallel, serve to return the reactor to the state of negative saturation during each half-cycle of e'_c. During the positive half-cycle, e'_c has no effect on the reactor because diode D_o is back-biased. The reactor, left to itself, remains negatively saturated once put in this state and presents such a low impedance to the driven AND-gates that they remain held at ground level during the negative half-cycle. Thus, binary zeros are transmitted.

If the AND-gates at the left of the diagram are not held at ground level during the negative half-cycle of e_c (which is opposite in phase to e'_c), a negative signal reaches the input winding of the reactor. Since this winding is in the opposite sense to that of the output, the negative signal saturates the reactor in the positive state during the positive half-cycle of e'_c. Finally, during the ensuing negative half-cycle of e'_c, the driven AND-gates return the reactor from positive to negative saturation. The reactor then presents a high impedance to the gates, so that they are not held at ground. The gates therefore transmit binary ones.

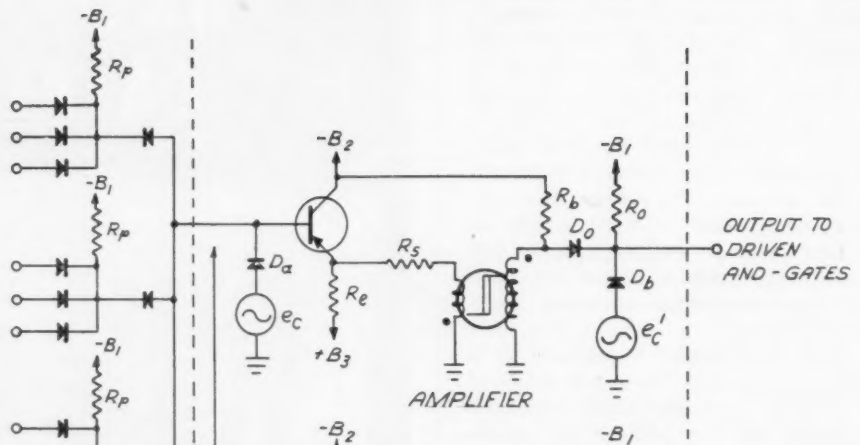

Fig. 1—Circuit diagram of transistorized magnetic core circuitry developed at the National Bureau of Standards for use in computers.

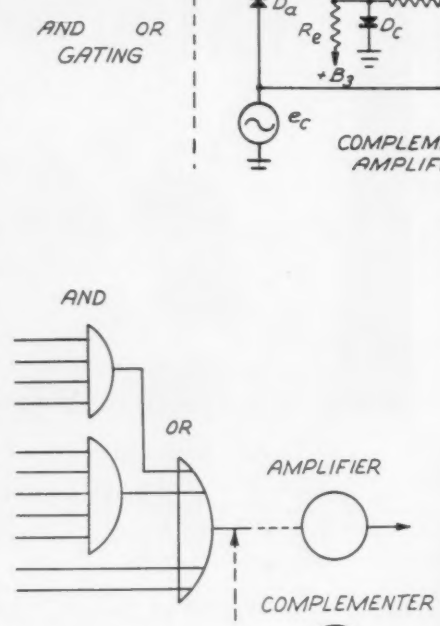

Fig. 2—Symbolic diagram showing the logical possibilities of the magnetic core circuits. In the circuits actually constructed, up to four-OR-inputs and five AND-inputs were used. The logical driving power of the AMP and COMP was around 30 each. Several hundred micro-microfarads of lead capacitance could also be driven in addition to the load. The clock frequency was 300 kc; its amplitude was 7 v rms.

CIRCUIT IMPROVEMENT DETAILS

The transistor emitter follower, having nearly unity voltage gain, does not change the basic operation of the origi-

nal circuit. However, it does improve the volt-second transfer function, and provides additional current gain. The current gain increases the logical gain of the stage and lowers the power expended in the interstage logical network. Improved volt-second transfer characteristic results from transistor base-charge storage which in turn results from driving the transistor into saturation at the peak of the pulse signal. Then, even though the pulse arriving at the OR-gate input may terminate very soon after the peak, the transistor base is not pulled down to ground potential at this instant because the OR-diode opens and the clock voltage holds up long enough to result in a full pulse at the emitter terminal. However, no storage and no reshaping take place if the signal fails to reach the value of the collector supply as in the case of no input pulse. To be sure that no false pulse gets through, current through the core secondary biases the core toward its "unset" state.

The complementer differs only slightly from the amplifier. The diode D_e and the base resistor R_e provide a current-limited low-impedance clamp to ground at the emitter. If a pulse is not transmitted by the emitter follower, the clock voltage applied to the core continually causes the core to receive and transmit pulses because the core magnetizing current is not large enough to open the clamping diode. But when a pulse is transmitted by the emitter follower, the diode opens, and the clock voltage impressed on the core directly is opposed by the pulse appearing at the emitter. The core therefore is left in the unset or no-pulse state and transmits nothing during the next half cycle. This complementer inserts only ½ cycle delay; the complementer of the original circuit inserted a full cycle of delay.

Final improvement in the previous circuit is the output AND-gate consisting of a pull-up resistor R_o and two diodes, D_o and D_b. The value of the resistor is adjusted to provide sufficient current to drive all the ground capacitance of the connecting leads-up to several hundred mmf—which run from the amplifier or complementer to all the gates driven by them. As a result, the current carried by a driven gate never need be greater than is required by the core directly associated with it. A single stage can drive as many as 30 other stages. The total power input to an amplifier or a complementer is around 0.5 watt and the power per singly loaded AND-gate is 0.15 watt. Clock power per core is approximately 50 milliwatts.

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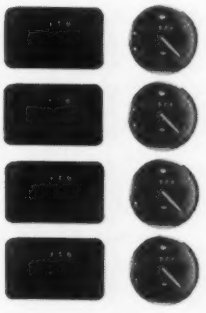

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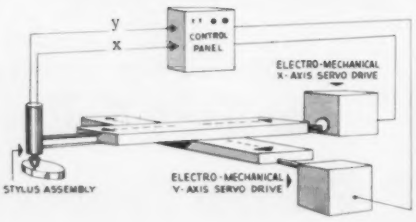
SYSTEMS DESIGN



2-D Tracer System

Economical two dimension tracer system, electro-mechanically controlled, will follow any contour around 360° path at a constant speed—regardless of direction. The value of the cutting speed can be varied manually, or can be automatically controlled as a function of spindle speed to maintain a constant feed rate in inches per revolution of the spindle.

Electro-mechanical design simplifies the tracer mechanism and considerably reduces initial cost as well as standard maintenance and repair requirements. According to the manufacturer initial cost will normally be from $1000.00 to $4000.00 below electrohydraulic or pure hydraulic systems. The system can be adapted to either computer or punched tape control.

The new tracer system incorporates a patented rotating eccentric stylus design. On contact with the template, the stylus assembly continuously feeds electrical signals to X and Y axis servo drives. These low power signals are boosted to actuate a mechanical amplifier which controls table movement for any value of the X and Y coordinate axes.

Other important characteristics are:

- The stylus can approach the template at any angle and when contact is made the system will automatically switch to the trace mode of operation.
- By varying the eccentricity of the stylus, the system will automatically compensate for tool wear.
- The stylus assembly servo motor permits (a) remote manual control at the table, (b) provides constant bias torque for automatic operation, (c) permits automatic control by tape or card for contouring without a template.
- The system will produce oversize template duplicates in controlled steps to facilitate the removal of materials that cannot be taken off in one pass. Seneca Falls Machine Co., Seneca Falls, N. Y.

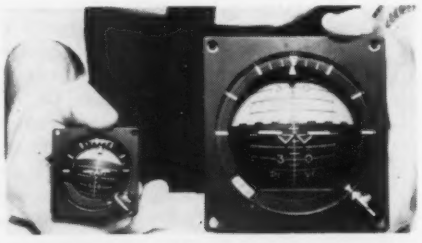
Circle No. 91 on Inquiry Card.

Two-Inch Attitude Indicator

A new attitude indicating system, developed by Lear, Inc., has a pictorial indicator engineered to fit into a standard two-inch-square cockpit panel cut out. The system is intended as a standby unit to replace an aircraft's primary indicating system in the event of a malfunction. Despite its reduced size and power requirements, it provides all the information found on the primary display and virtually equals the accuracy of the primary system. A miniaturized attitude indicating system, independent of the primary display, is becoming an increasingly essential safety feature in today's manned weapons systems. Interest by the military in equipping high-performance jets with a dual installation points up the vital role the attitude indicating system has come to assume in all-weather aircraft operation. The pictorial indicator displays pitch and roll attitude by movement of a light grey and optical black sphere behind a fixed, symbolic aircraft. A 1.5:1 gearing in the pitch axis provides increased sensitivity of the pitch attitude for maximum readability. Electrical trim for both pitch and roll is included.

The indicator is hermetically sealed and includes two interchangeable transistor amplifiers. Servo loops are 70 per cent critically damped for smooth, sensitive operation. The system can be operated from either an a-c or a d-c power supply.

Heart of the system, Lear's new Series 1080 miniature vertical gyro, is a compact vertical reference designed specifically to provide reliable operation in those severe shock and vibration environments encountered in missiles, drones, and high-performance aircraft.



Comparison of the new Lear two-inch remote standby indicator, part of the smallest attitude indicating system yet built for the aircraft industry, with a standard five-inch attitude indicator.

Following a proven packaging philosophy, system engineers have mounted the gyro reference remotely from the indicator package to provide a gyro of sufficient size to maintain the accuracy of the primary system.

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Subminiature Commutator

A miniaturized 30 x 10 2 pole telemetering commutator is only 2½" square by 4" long including a self-contained motor, gear box and switching section. Displaying less than 0.3% noise levels with milli-volt input signals, the life of the switch is in excess of 1,000 hrs. Instrument Development Labors., Inc., Attleboro, Mass.

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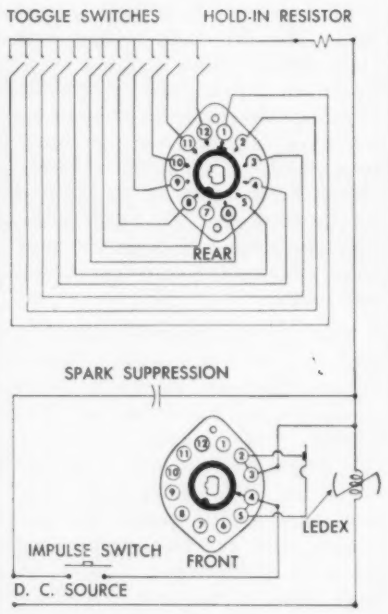
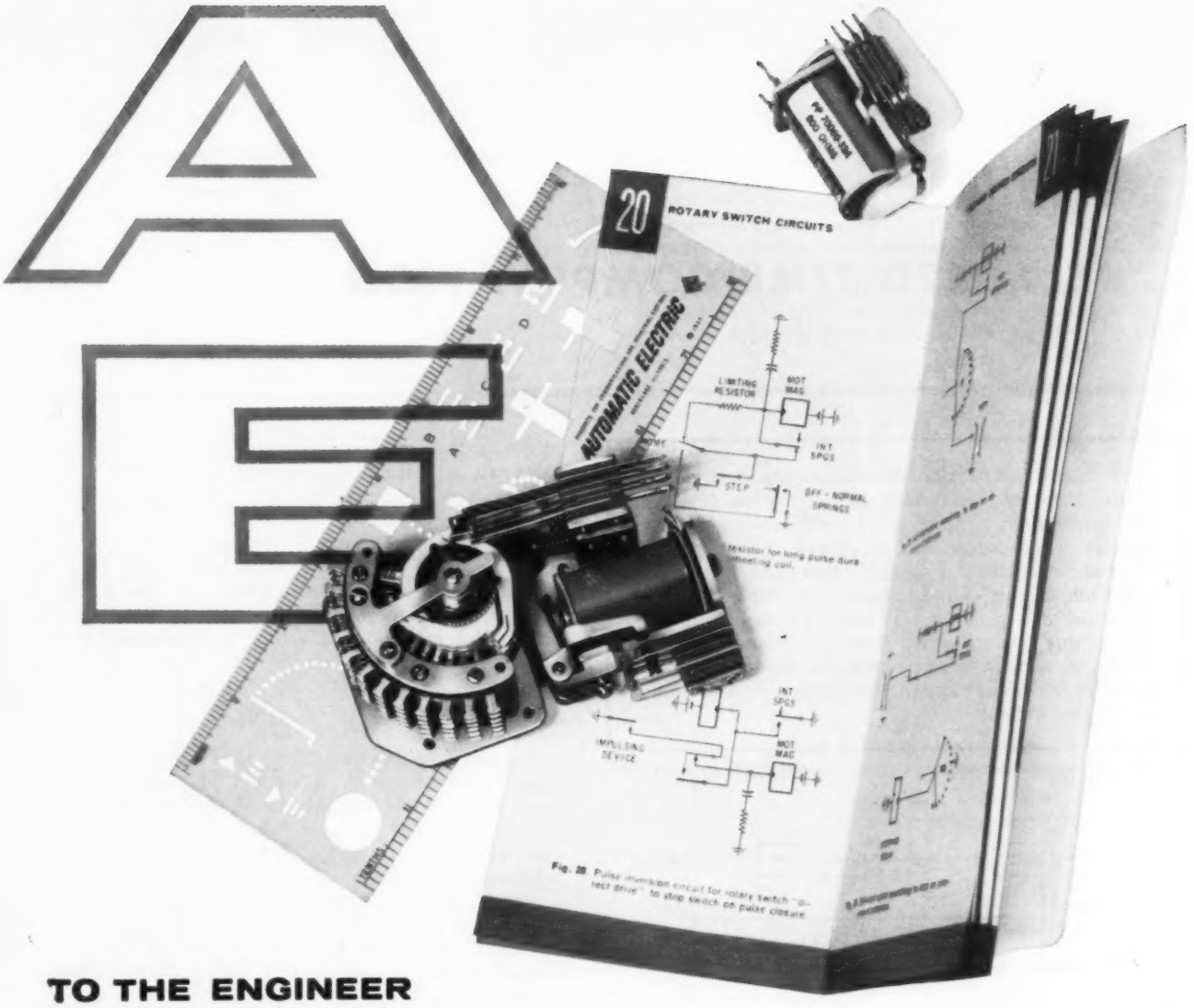


Leland Variable Programming Circuit

Variable Programming Circuit

A variable programming circuit described in the diagram employs a new rotary selector to control and change the sequence of functions in automatic equipment. The rotary selector uses an inverse-homing, tab-type control-wafer switch which in conjunction with a hold-in resistor, will cause the selector, when impulsed, to skip over the unwanted positions. Variations in positioning of the selector are accomplished by placing a toggle switch between the hold-in resistor and each homing contact. An open toggle switch permits the selector to step past that position automatically when the impulse switch is closed. This occurs because the Ledex rotary solenoid is energized only through the interrupter switch. If the toggle switch is closed, the resistor will be placed in parallel with the interrupter switch and if opened the hold-in resistor is placed in series with the coil. The solenoid therefore remains energized at the position until the impulse switch is released, causing the selector to stop until another impulse is received. G. H. Leland, Inc., Dayton, Ohio.

Circle No. 165 on Inquiry Card



TO THE ENGINEER

who needs "for instances"

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NEW TECHNIQUES

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ELAPSED TIME COMPUTATION

Here is an inexpensive technique, reported at the recent National Electronics Conference in Chicago, for performing a number of arithmetic operations reliably where accuracies in excess of one percent are not required. One simple semiconductor circuit, using amplitudes of independently variable electrical quantities as inputs, can be made to perform any of the various operations by interchanging the roles of the input signals. Modifications in the basic circuit adapt it to various combinations of analog and digital inputs and outputs.

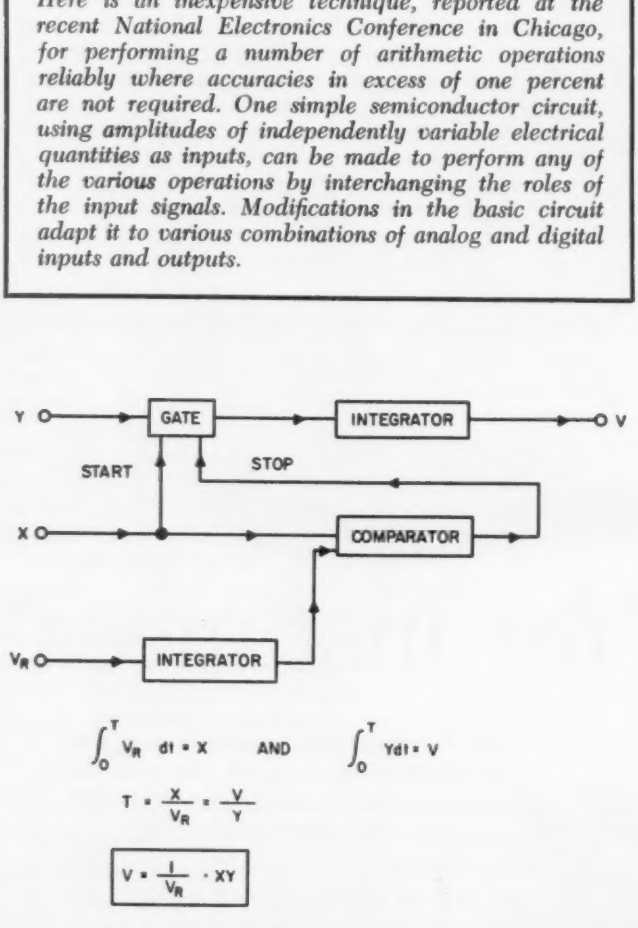


Fig. 1 Princip'e of elapsed time division. D-c signals x and y are applied simultaneously at the input terminals. X acts as a signal to open the gate, allowing the reference voltage to be applied to the upper integrator. X is also applied directly to a comparator where it is continually compared to the integrated value of y that is being fed in from the lower integrator. The comparator eventually notes that the integral of y is exactly equal to x. This will occur at some time T depending on the values of x, y, and the fixed time constant of the integrator. The comparator now generates a stop signal, closing the gate and preventing V, the integrated value of V_R, from increasing further. The peak value of V is proportional to the required division of x by y.

Multiplication, division, squaring and square root operations can be accomplished simply and accurately by means of a class of computational circuits employing time as an intermediate parameter. To perform a division operation, for example, one variable is integrated with respect to time until the value of the integral is numerically equal to the second variable. The time required for this integration is proportional to the ratio of the two variables. A reference voltage integrated for this time is a measure of the time and therefore of the required ratio. Since both integrators operate for the same amount of time, errors due to imperfect integration will cancel provided that the two integrators have similar characteristics.

Input and output quantities may be represented by either analog voltages or by a number of pulses. In the latter case, many of the advantages of digital computation may be obtained. For example, elapsed time (time-base) circuits use the active device (transistor) in a switching mode resulting in a substantial increase in reliability.

Time-base circuits are basically sampling circuits. In the problem of finding the ratio of the two time-varying input variables, the signals must first be sampled at a sampling frequency that is considerably higher than the signal frequency. Signals in the form of short pulses, on the other hand, may need to be stretched or held to allow sufficient time for computing their ratio. If the inputs are d-c quantities they may be operated on directly. Such d-c inputs are assumed in most of the explanations that follow. This assumption results in no loss of generality since the sampling or hold processes convert the inputs to values that do remain essentially constant for the case of non d-c signals. Similarly, the results of the computations are non-continuous and provision must be made for holding results of one computation until a new result is available. Clearing and hold functions may usually be realized very simply.

DIVISION

Figure 1 is a block diagram describing the principles of the time-base division process. The circuit consists of a gate, two integrators, and a voltage comparator. The inputs to the circuit are the two d-c voltages x and y whose ratio is desired, and a d-c reference voltage V_R. The figure shows that the output voltage V, measured at the proper time, is proportional to x/y.

Equations that apply to the operation are summarized on the figure. T is the elapsed time from the start of the operation until the comparator signals that the integrated value of y is equal to x. Note that T itself is equal to x/y. The upper integrator may be thought of as simply a technique for measuring the time T.

Analog division circuit. Usefulness of this elapsed time computation technique in many applications results from the fact that very simple circuits may be used to realize the system. Fig. 2 is an example of a circuit designed to

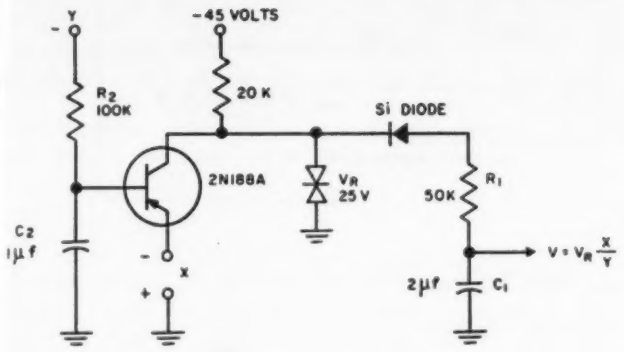


Fig. 2 Elapsed time divider. Assume that the transistor is normally conducting in standby operation. This would occur, for examp'e, if the voltage source X is zero and some negative voltage y is present. This transistor therefore acts as a short circuit and no voltage is applied through the silicon diode to R_1C_1. Now to begin the computation of x/y the d-c voltage x is applied between the emitter of the transistor and ground. This cuts of the transistor and causes the reference voltage V_R to rise to exactly 25 volts. R_1C_1 integrates this reference voltage; R_2C_2 integrates the voltage y. When the integrated value of y that appears across C_2 is equal to x the transistor will again conduct. This serves as the stop signal for V_R by reducing the voltage available to the reference diode. The value of V appearing across C_1 at this time is proportional to the required ratio x/y. The silicon diode prevents C_1 from discharging, thus allowing V to be measured easily.

operate on the principle of Fig. 1. The transistor acts as the gate and as the comparator. The RC networks R_1C_1 and R_2C_2 serve as the upper and lower integrators respectively and a breakdown diode constitutes the reference voltage.

If the time constants R_1C_1 and R_2C_2 are made equal it may be shown that no error results from the fact that these are not really integrators. Actually all that is required is that the time response of V relative to V_R be the same as the time response of the signal applied to the base of the transistor relative to the y input. In this circuit the values of R's and C's that were chosen lead to a slow computation process. Much higher speeds may be achieved, if desired, by selecting smaller values.

The dynamic range of this circuit is limited on the upper end by restricting x to values of voltage that are smaller than the inverse breakdown voltage of the emitter-to-base diode of the transistor. The lower bound is set by the transistor in its comparator function since it actually requires a few tenths of a volt bias of the base-to-emitter diode to cause conduction from collector to emitter. Somewhat more elaborate comparator and gate circuits can be used to extend the dynamic range considerably.

Interpolation. Variations of the circuit in Fig. 2 can be used to achieve combinations of mathematical operations. For example if V_R is replaced by constant values of another variable z, the result would be $V = zx/y$. Another example, this time incorporating addition, is illustrated in Fig. 3. Here the problem is to interpolate between the values x and y; i.e., the value $x/(y + y)$ now charges C_2 rather than y alone. The comparator therefore operates when the integrated value of $(x + y)$ is equal to x. Note also that x is now a positive voltage relative to ground while y is negative requiring an inversion of the x signal relative to the previous circuit.

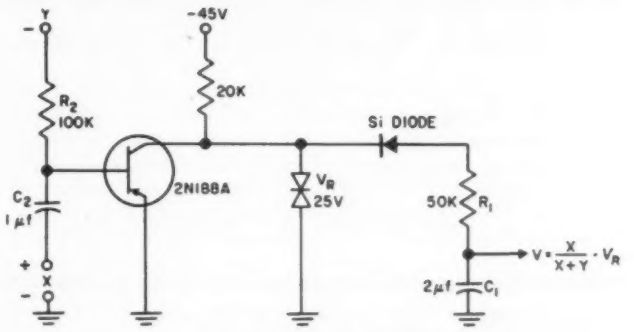


Fig. 3 Interpolation circuit.

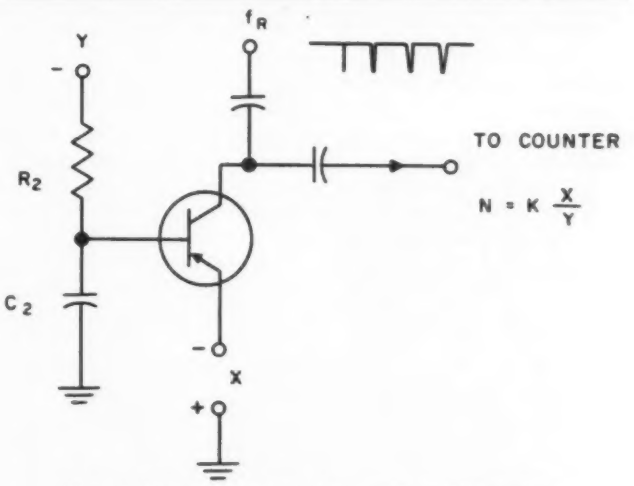
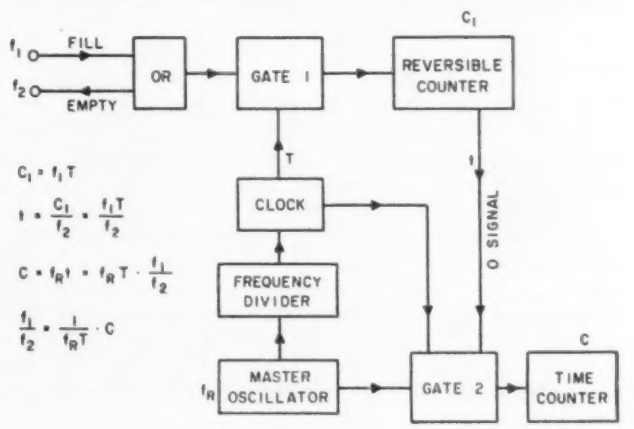


Fig. 4 Elapsed time divider with digital output.

Fig 5 Elapsed time digital divider. Frequency f_1, the smaller of the two, is fed in through gate 1 to a counter which registers a count C_1 at the end of the fixed time interval T. Logic circuits preceding the computational circuits decide whether $f_1 > f_2$ or vice versa and guide the lower frequency to the f_1 position. (S'milar logic is required for the analog schemes since these circuits are designed to operate only for ratios less than unity.) Now the clock connects the f_2 input to the reversible counter through gate 1. (The counter is reconnected now so that each input pulse will subtract one unit from the remaining count.) At the same time gate 2 is opened, allowing pulses from the reference source f_R to enter the time counter. Now since $f_2 > f_1$, the reversible counter will count back to zero in time t (less than T). When the counter indicates O, a signal is given to close gate 2 preventing any more pulses from entering the time counter. The final state of the time counter is therefore a measure of t and hence of the ratio f_1/f_2.



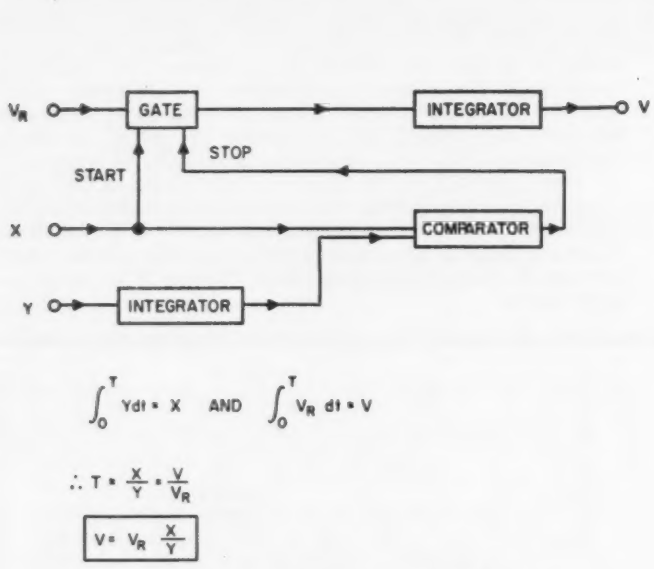


Fig. 6 Elapsed time multiplier.

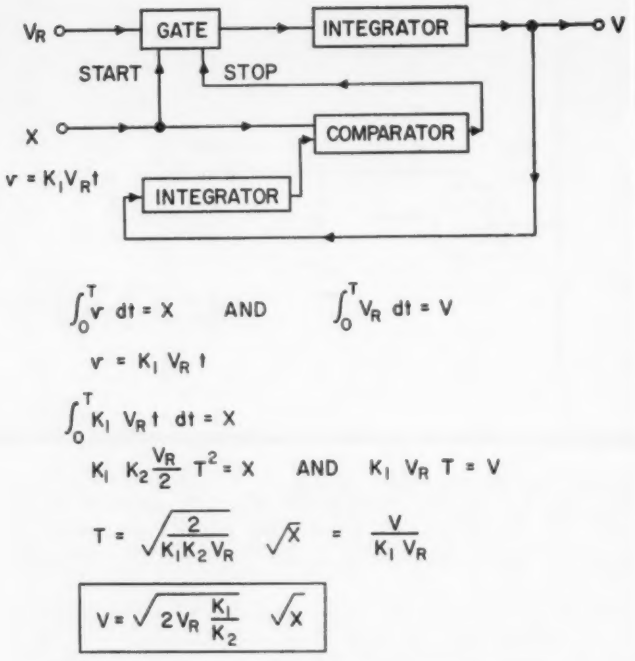

V_R
GATE
INTEGRATOR
V
START
STOP
X
COMPARATOR
$v = K_1 V_R t$
INTEGRATOR
$\int_0^T v\, dt = X$ AND $\int_0^T V_R\, dt = V$
$v = K_1 V_R t$
$\int_0^T K_1 V_R t\, dt = X$
$K_1 K_2 \frac{V_R}{2} T^2 = X$ AND $K_1 V_R T = V$
$T = \sqrt{\frac{2}{K_1 K_2 V_R}}\ \sqrt{X} = \frac{V}{K_1 V_R}$
$V = \sqrt{2 V_R \frac{K_1}{K_2}}\ \sqrt{X}$

Fig. 7 Block diagram of square root operation.

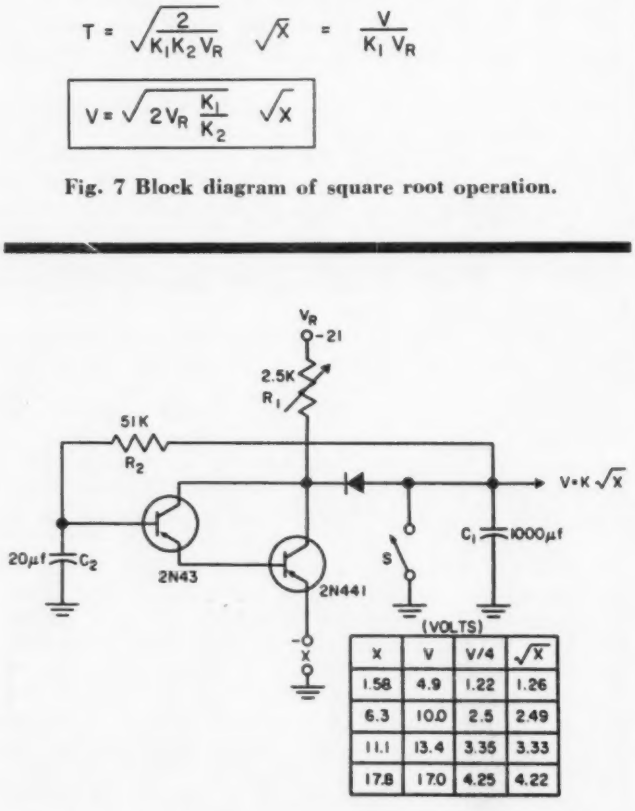
ANALOG-DIGITAL CONVERSION

Another useful property of the time-base computation principle is the ease of using the process as a means for converting from analog representation to pulse representation while performing a calculation. Figure 4 illustrates a division operation in which the inputs x and y are d-c quantities, but their ratio is taken as a discrete number of pulses. The input circuit (including R_2C_2, the d-c x and y inputs, and the transistor) operates in the same manner as that of Fig. 2. In Fig. 4, however, the reference voltage and the second integrator are replaced by a reference frequency and a counter respectively. Pulses at the reference frequency f_R are prevented from entering the counter except during the time that the transistor is non-conducting. The number of pulses that do enter the counter is then a measure of T and hence of x/y. The result of the division therefore appears in either a binary or a decimal form depending on the type of counter that is used.

The counter is a perfect integrator while the RC network is only an approximation. Hence provision must be made for taking this condition into account. This may be done either by feeding C_2 from a current source (linearizing the output of the RC circuit) or by automatically varying f_R to compensate for the characteristic of the RC network. Both methods are entirely practical.

PULSE TECHNIQUE

Thus far the discussion has been concerned mainly with analog time-base computation. The technique lends itself readily to pulse or to digital systems. One scheme that may be used for finding the ratio of two inputs each of which is a frequency or rate is illustrated in Fig. 5. Again, as in Fig. 1, a comparator is used to compare one input with a time-dependent function of the second. Here the comparison takes place by means of the reversible counter C_1. F_R, a reference frequency, is counted by time counters C to measure time t required for the comparison of the two inputs. It may be seen from the equations of Fig. 5 that $t = (f_1/f_2)T$ and that the basic problem is again just the measurement of t.



X	V	V/4	$\sqrt{X}$
1.58	4.9	1.22	1.26
6.3	10.0	2.5	2.49
11.1	13.4	3.35	3.33
17.8	17.0	4.25	4.22

Fig. 8 Circuit diagram of square root operation. The two transistors are connected in the Darlington compound connection and act as a single common-emitter stage with a current amplification that is the product of the alphas of the individual transistors. The advantage of this connection for this application is the resulting higher input impedance of the combination. A single transistor will often serve as this element. The compound transistor acts as the gate and as the comparator as in Fig. 2. The reference voltage is V_R, the upper integrator is R_1 C_1, and the lower integrator is R_2C_2. The input to R_2C_2 is taken from C_1; i.e., the voltage on C_1 at any time is integrated by R_2C_2 and this integrated value is applied to the base of the compound transistor for comparison with x. When switch s is opened and x is applied, C_1 begins to charge through R_1 and C_2 charges through R_2. The compound transistor conducts when its base-to-ground voltage is equal to x. The voltage V across C_1 at this time is K times the square root of x. The table of Fig. 8 shows some actual measured values of V/4, (K = 4), compared to calculated values of the square root of x. Note that the agreement is very good even for values of x approaching the reference voltage.

The precision of the time measurement depends on the frequency f_R, increasing for higher values of f_R. Since f_R is synchronized with the clock by the frequency divider, extremely high frequency stability is not required from the f_R source. It should be noted also that f_1 and f_2 need not be fixed frequencies. One or both may be varying around some average value in a random manner and the system will still function as described.

MULTIPLICATION

The elapsed time principle may be used to perform multiplication as well as division. Essential similarity of the two processes will be seen by comparing the divider block diagram (Fig. 1) with the multiplier diagram of Fig. 6. The only change has been to interchange the V_R and y inputs. An integrated value of V_R is now compared to x and the output V is the integrated value of y obtained in the time required for the comparator to indicate that its two inputs are equal. The equations in Fig. 6 clarify the multiplication process. The circuit of such a system will be the same as that of the divider shown in Fig. 2 with the positions of V_R and y interchanged as in the block diagram.

SQUARE ROOT

The process of extracting a square root is illustrated in the diagram of Fig. 7. Again the basic block diagram is the same as that shown for division in Fig. 1. For the square root operation, however, there is only one independent input variable x. The y input is replaced with a feedback connection from the output terminal. Thus the integrated variable to which x is compared is itself a function of time. As shown in the equations of Fig. 7, the integral equation for the lower integrator therefore contains t explicitly resulting in a T^2 term in the definite integral. Hence T is proportional to the square root of x. The upper integrator measures T and at the same time provides $v = K_1 V_R t$ as an input to the lower integrator. Figure 8 is a square root circuit employing the principle illustrated in Fig. 7.

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MATERIALS

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SO WHAT ELSE IS NEW?

The Fall Meeting of the American Chemical Society in Atlantic City had some interesting new developments to report in the field of materials development. As usual, plastics technology was one of the fields that showed considerable activity.

A new lightweight plastic composition was described by F. T. Parr of Westinghouse Electric Corp. This composition consists of microscopic phenolic resin balloons distributed in an epoxy resin matrix. Chief virtues of this "micro-balloon" filled resin are a reduction in weight of 27% over conventional fillers and superior heat conduction compared with foamed polyurethane resins. An additional advantage of the microballoon filled resin is reduced tendency toward heat cracking during temperature cycling and superior resistance to humidity.

V. R. Bond and S. A. Brady of Dow Corning Corp. described a new silicone-epoxy resin for laminates. Low pressure laminates prepared with silicone-epoxy resins maintained their initially high structural strength after long time aging at 500°F.

G. Epstein and S. Litvak of Aero-Jet-General Corp. discussed the influence of fabrication variables on metal-to-metal bonding. Improved surface preparation, particularly primer coatings and degree of primer cure, greatly influenced bond strength. Air entrapment in the liquid adhesive was found to be an important factor, influencing the tensile-shear strength of the adhesive bond as well as the type of failure. The amount of pressure during cure had a noticeable effect on lap shear strength of metal bonded joints. Resolution of these fabrication variables has aided in development and fabrication of newly conceived military hardware.

Recent developments in fluorosilicone elastomers were described by T. D. Talcott, E. D. Brown and J. K. Russell of Dow Corning Corp. These elastomers exhibit excellent resistance to swelling in oils and solvents while retaining the usual physical properties of the silicones. A new room temperature vulcanzing compound based on fluid fluorosilicone polymers was announced. These new elastomeric materials are useful wherever resistance to swelling and serviceability over the extreme temperature ranges provided by silicone elastomers is required.

Use of polychlorotrifluoroethylene oils and resins as gyro flotation fluids was discussed by R. L. Ehrenfeld of Fluoro-Chem Corp. Flotation fluids must be used in cases where extreme accuracy is necessary, as in inertial guidance systems, where gimbal bearing friction errors cannot be tolerated. Flotation fluids must also have high densities, 1.8 or over, to avoid bulky packages and decrease flotation errors. Proper damping characteristics require viscous oils. The most effective fluid developed was a blend of low molecular weight bromotrifluoroethylene polymers with polychlorotrifluoroethylene oil and solid polymer to control the viscosity.

Fluorocarbon fluid properties and applications were discussed by J. D. LaZerte, M. Olyphant and J. M. Smith of Minnesota Mining and Manufacturing Co. A proprietary product, FC-75, has found applications in electronic components and instruments. FC-75 is an excellent dielectric coolant. Dielectric strength of the liquid and vapor is high. The low viscosity and surface tension are advantageous in convective cooling. The boiling point of 100°C allows the use of evaporative cooling. All of these factors are useful in miniaturization. FC-75 can be used in equipment at temperatures down to −100°C. The high thermal stability allows cooling of hot spots without formation of sludge or corrosive products.

FUEL CELLS

Intensive development of fuel cells has been carried out in this country and in England over the past five years. Fuel cells offer an attractive possibility for the direct conversion of chemical energy without the usual intermediate heat engine. Theoretically, all chemical reactions releasing heat energy can also be made to furnish electrical energy under the proper conditions. Chemical batteries are an illustration of this principle. Hydrogen and oxygen can be combined by combustion to release a large quantity of heat. Under combustion conditions, however, an intermediate heat engine of some kind must be used to convert heat of combustion to electrical energy. If the "combustion" were to be conducted under conditions where an electrode reaction could take place, the energy would appear directly as electrical energy. The problem of practical electrodes has been the barrier to using this method of direct electrical energy conversion from combustible fuels. Considerable progress has been made along these lines and various types of fuel cells were discussed at a symposium.

Conversion efficiencies of 70% were reported by K. Kordesch of National Carbon Co., using carbon electrodes. Open circuit potential of hydrogen-oxygen cells was 1.13 volts. Current densities up to 200 ma. per sq. cm. (1 sq. in. = 6.25 sq. cm.) were obtained above 0.8 volts. Continuous and intermittent operation over a 2 year period have been achieved. The oxygen electrode is limited to alkaline cells, but the hydrogen electrode works equally well in acid cells.

A high pressure hydrogen-oxygen fuel cell and a multicell design complete with control gear were described by F .T. Bacon of National Research Development Corp., Cambridge, England. Other fuel cells were discussed that use gaseous hydrocarbons and carbon monoxide as the fuels. Operating temperatures up to 650°C. have proved feasible.

New hope appeared on the ulcer front. An extract of dried seaweed, carrageenin, has been found to inhibit peptic ulcers. Six dogs that were given histamine to induce peptic ulcers all died within a month. Six dogs similarly treated but permitted to drink water containing carrageenin were still alive. Dried seaweed—anyone? Wuff!

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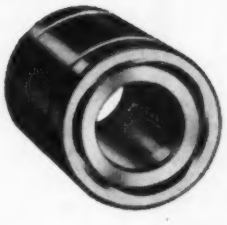

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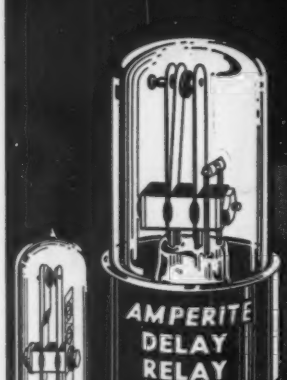

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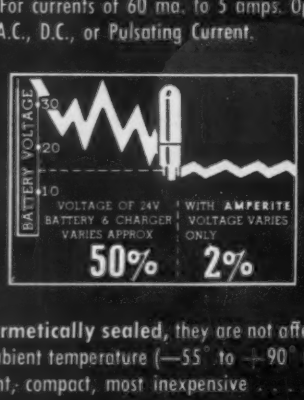

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MANAGEMENT

STAFF COLUMNIST

Hyman Olken

LAWRENCE RADIATION LABORATORY

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Livermore, California

Inducing the Inventive Spark

An exasperating aspect of inventing universally experienced by inventors is that, cudgel their brains as they will, they frequently just can't get the process of forming and testing combinations of mental images going; or, if they do get the process going they have no control over its direction. In brief, inventing is a sporadic and unpredictable process.

To practice inventing professionally, some measure of control over getting the process going and directing it is vitally necessary. The problem for the inventor is *what are the roadblocks to this control and what can be done to remove or overcome them? What can be done to induce the inventive spark?*

The Anatomy of Inspiration. One key to controlling the inventive process is to recognize the sporadic nature of the mechanism we are dealing with. The human mind is not a highly specialized machine designed only to invent. It is a very complex machine required to perform many functions to preserve and regulate the human body before it can give attention to inventing. Inventing is merely an extraneous function crowded in on top of all these regular functions.

Because inventing is such an interloper, it is a very unpredictable, and devious procedure, which occurs only when the mind has a few idle moments. This occurs generally when we are mentally at rest—usually before going to sleep, just after waking, or when we are going through actions that have become habitual and so do not fully occupy the mind. It is a commonplace observation of inventors that most of their inventive thinking occurs at such times.

Another key to understanding the inventing process is to be found in the intensive studies psychologists have made into creative mental processes. They have shown that these processes can best be analyzed if they are divided into four stages:

- **Preparation**—prepares the ground for the attack by accurately defining the problem and collecting the raw materials (the idea elements) from which the desired idea compounds are to be formed.
- **Incubation**—digests the idea elements and probes toward a solution of the problem.
- **Illumination**—where the solution bursts suddenly upon the mind, like a flash of light.
- **Verification and Elaboration**—tests this solution and extends its application.

Idea elements—the raw materials of invention—must be in the mind before they can be combined or synthesized into idea compounds. The process of storing the ideas is sometimes consciously directed; more often, it takes place unconsciously and may extend over a very long period of time. Idea elements enter the mind when we read a technical article, when we observe the operation of a machine, and when we accomplish a mathematical analysis or carry out a scientific research. The dominant characteristic of the process is that, after the inventor has planted the seed of an invention and toiled over it for some time without

success, he then seemingly abandons it to the subconscious regions, where it may lie dormant for a very long time, until one day, entirely unexpectedly, the full grown invention pops suddenly into light.

What goes on in the inventor's mind during all this time? Why so long a dormant or incubation period? What is the mechanism of the sudden fulfillment?

Psychologists have demonstrated that ideas are like people—they don't want to be alone. They usually enter the mind in clumps or clusters. When we want to combine an idea from one cluster with an idea from another to form a new combination, we must first separate the idea elements from their foetal entanglements. This is one of the actions that goes on during the "incubation" stage. As one psychologist has so aptly put it, (see Varendonck, J., **Evolution of the Conscious Faculties,** G. Allen & Unwin, London, 1923, p. 9) "Conception consists of a decomposition of memory and a re-association of its elements."

We all know, however, from life-long experience that ideas persist in their associations. They do not dissociate until time has weakened their bonds. Over this dissociating process the mind has no deliberate control. Time is the only solvent. This is one of the reasons why the incubation process takes so long.

Once dissociated, the idea elements must also be fed up from the dim recesses of the memory to where their trial-and-error matching to a desired pattern goes on. Here progress is often retarded, or even completely blocked, by cross currents in the brain or by other more recent or more urgent ideas which command prior right of way. Here the mind does have some measure of deliberate control. Such measures are fully treated in all standard psychology texts under the subjects of "interference" and "recall".

The bulk of the activity in the mind during the incubation period is the "re-association of the elements of the memory" into new combinations. As indicated in an earlier section of this column, "the mind first forms a concept or image of what it aims to accomplish. Idea elements are matched for fit in this concept as they flow up from the dim recesses of the mind. Misfits are discarded."

A common observation of inventors and psychologists alike is that this matching of idea elements is done gropingly at first. But this groping is not entirely random. It is like the groping of a person finding his way in a dark but familiar room or trying to solve a cross-word or jig-saw puzzle. Each piece successfully fitted into the puzzle reduces the number of pieces to choose from for the next move and provides more orientation for fitting the next piece into place. The process of groping becomes better guided and directed, hence easier and faster, the further the process has gone toward completion.

We have here a clue as to what may take place in the "illumination" stage of inventing. When the process of trial-and-error matching has gone so far that each piece fitted into the desired pattern indicates fully and accurately how the next fitting operation should be made, the remainder of the elements fit into place without trial and with no error. Each move in the matching operation automatically calls forth the next move to make and the process becomes self-propagating and self-accelerating, taking on the character of a chain reaction. The moves for completing the idea combination then occur so rapidly that the mind is not able to follow them separately and the whole series seems to take place in a "flash". Many experimental psychologists who have studied the problem solving process now lean toward this view that the "illumination" stage is merely an acceleration of the incubation process. There is a striking similarity here to the process of explosion. Physicists have shown by slow-motion analysis that an explosion is not a peculiar phenomenon but merely a highly accelerated form of "combustion".

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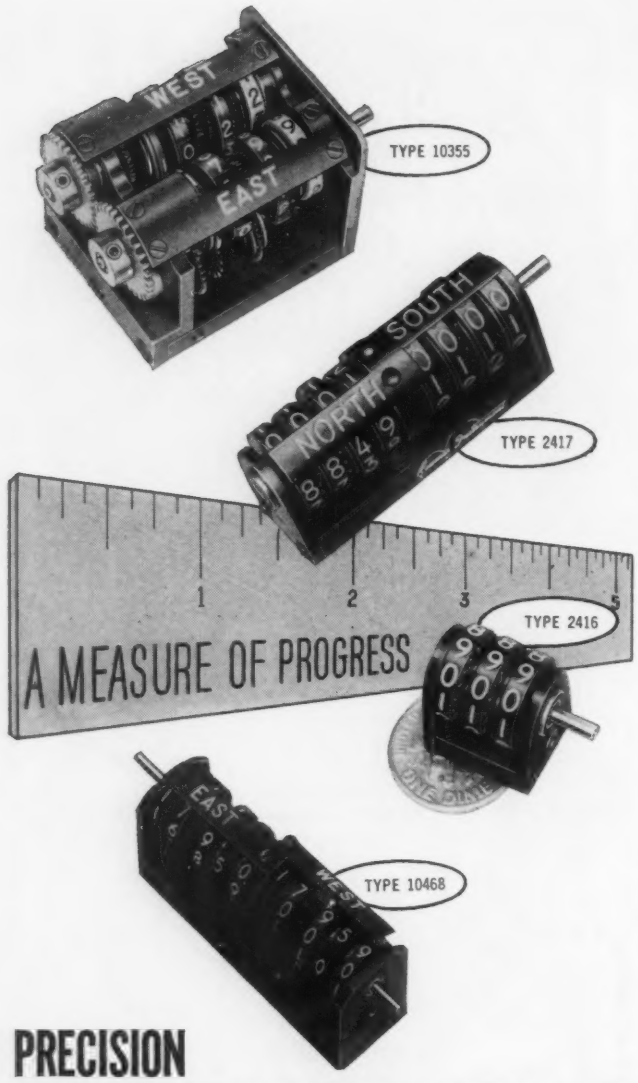

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CALCULATION OF NATURAL FREQUENCIES OF DAMPED SYSTEMS

by

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Matrix iteration methods have been used extensively to determine the natural modes of free vibration of mechanical systems. In most instances, the effect of viscous damping is neglected in these calculations, since the quantity of damping in many physical systems is small and therefore will not appreciably modify the value of the undamped natural-frequency calculations. Also, the problem of exactly determining the natural modes of free vibrations of a multi degree-of-freedom damped vibration system by matrix methods involves a considerable amount of calculation. A method using matrix iteration for calculating the frequencies of damped systems has been presented by W. J. Duncan in *Matrices Applied to Motion of Damped Systems.* Any method used in calculating the natural frequencies and modes of vibration for a damped system involves a considerable amount of labor.

In many instances, particularly for approximately equal damping values, satisfactory solutions for the motion of the damped system can be arrived at with less difficulty by the following technique:

Do not consider the damping in the original equations of motion, but use any standard procedure for undamped systems to calculate the natural frequencies and modes of free vibration. These frequencies and modes of vibration can then be modified to account for damping.

For example, consider the problem of determining the natural modes of free vibration of a mechanical system consisting of 3 spring-suspended masses in series.

Neglecting damping, the equations of motion are of the form:

$$\begin{aligned} M_1(d^2y_1/dt^2) &= K_2(Y_2 - Y_1) - K_1Y_1 \\ &= -(K_1 + K_2)Y_1 + K_2Y_2 \\ M_2(d^2y_2/dt^2) &= K_3(Y_3 - Y_2) - K_2(Y_2 - Y_1) \\ &= K_2Y_1 - (K_2 + K_3)Y_2 + K_3Y_3 \\ M_3(d^2y_3/dt^2) &= -K_3(Y_3 - Y_2) = K_3Y_2 - K_3Y_3 \end{aligned} \qquad (1)$$

The natural modes of vibration are specified by equations of the form:

$$\begin{aligned} Y_1(t) &= X_1 \sin(wt + \alpha) \\ Y_2(t) &= X_2 \sin(wt + \alpha) \\ Y_3(t) &= X_3 \sin(wt + \alpha) \end{aligned} \qquad (2)$$

Introducing equation (2) in (1) we obtain:

$$\begin{aligned} (K_1 + K_2)X_1 - K_2X_2 &= M_1\omega^2X_1 \\ -K_2X_1 + (K_2 + K_3)X_2 - K_3X_3 &= M_2\omega^2X_2 \\ -K_3X_2 + K_3X_3 &= M_3\omega^2X_3 \end{aligned} \qquad (3)$$

In the special case when

$$K_1 = K_2 = K_3 = K \quad \text{and} \quad M_1 = M_2 = M_3 = M$$

these equations reduce to:

$$\begin{aligned} 2X_1 - X_2 &= \gamma X_1 \\ -X_1 + 2X_2 - X_3 &= \gamma X_2 \\ -X_2 + X_3 &= \gamma X_3 \end{aligned} \qquad (4)$$

if we set

$$\gamma = 1/\lambda = M\omega^2/K$$

where the λ's are characteristic values.

Solution of equation (4) by matrix iteration or otherwise (refer to any standard text) leads to:

$$M\omega^2{}_{1n}/K = 1/5.05;$$
$$\omega_{1n} = 0.445\,(K/M)^{1/2}$$

with displacement ratios:

$$(X_1{:}X_2{:}X_3) = (0.445{:}0.802{:}1)$$

and to:

$$\omega_{2n} = 1.247(K/M)^{1/2}$$

with displacement ratios

$$(X_1{:}X_2{:}X_3) = (-1.247{:}-0.555{:}1)$$

and to:

$$\omega_{3n} = 1.802(K/M)^{1/2}$$

with displacement ratios

$$(X_1{:}X_2{:}X_3) = (1.802{:}-2.247{:}1)$$

The damped frequencies can now be determined by the following consideration; in a single-degree-of-freedom system the damped frequency is related to the undamped frequency by the following equation:

$$\omega_{nd} = \omega_n(1 - \rho^2)^{1/2} \qquad (5)$$

where

$$\rho^2 = (r/r_c)^2$$

and

$$r_c = 2(KM)^{1/2} = 2\omega_n M \qquad (6)$$

In a multi degree of freedom system, where

$$r_1 = r_2 = r_3 = r$$

the relationship between the damped and the undamped frequencies becomes:

$$\omega_{1nd} = \omega_{1n}(1 - \rho_1{}^2)^{1/2}$$

where

$$\rho_1{}^2 = [r/(2\omega_{1n}M)]^2 = r^2/[(4)(0.445)^2KM]$$
$$= r^2/(0.795KM)$$

and similarly

$$\omega_{2nd} = \omega_{2n}\,(1 - \rho_2{}^2)^{1/2};$$
$$\rho_2{}^2 = [r/(2\omega_{2n}M)]^2$$
$$= r^2/[(4)(1.247)^2KM] = r^2/(6.25KM)$$

and

$$\omega_{3nd} = \omega_{3n}\,(1 - \rho_3{}^2)^{1/2};$$
$$\rho_3{}^2 = [r/(2\omega_{3n}M)]^2$$
$$= r^2/[(4)(1.802)^2KM] = r^2/(13.8KM)$$

In order to demonstrate the above method, the simplification: $K_1 = K_2 = K_3$ and $M_1 = M_2 = M_3$ was used. The method is equally applicable to $K_1 \neq K_2 \neq K_3$ and $M_1 \neq M_2 \neq M_3$. What has been presented is a method by which, after the natural frequencies and modes of vibration for an "equivalent undamped" system are found (by whatever method is convenient), one may easily find the natural frequencies and modes of vibration for the damped system.

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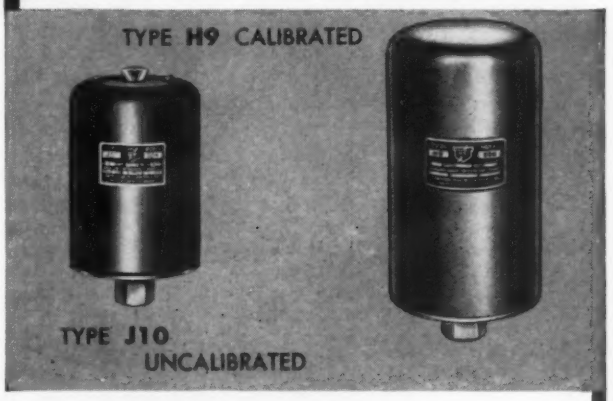

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WORTH FILING

Audio Measurements Techniques

Frequency response and distortion measurements of amplifiers are discussed in "The Panoramic Analyzer". Automatic techniques for testing tape and disc recorders and pickups are also described. This booklet outlines how tedious point by point measurements of audio-frequency response and distortion can be avoided by the use of an automatic scanning audio-frequency spectrum analyzer.

Source: Panoramic Radio Prods., Inc.
Mount Vernon, New York
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Specialty Steel Buyers' Guide

Excellent reference source is 40 page guide containing information on tool and die steels; stainless steels; high temperature alloys; electronic magnetic and electrical alloys; special purpose alloy steels; tubing and pipe and fine wire specialties. Includes tool steel selector chart which provides a system of matching tool steels. Numerous tables show the properties and workability of major types of stainless steel and high temperature alloys. Section on electronic alloys contains graphs which compare expansion characteristics, electrical resistance, permeability, and magnetic flux density.

Source: The Carpenter Steel Co.
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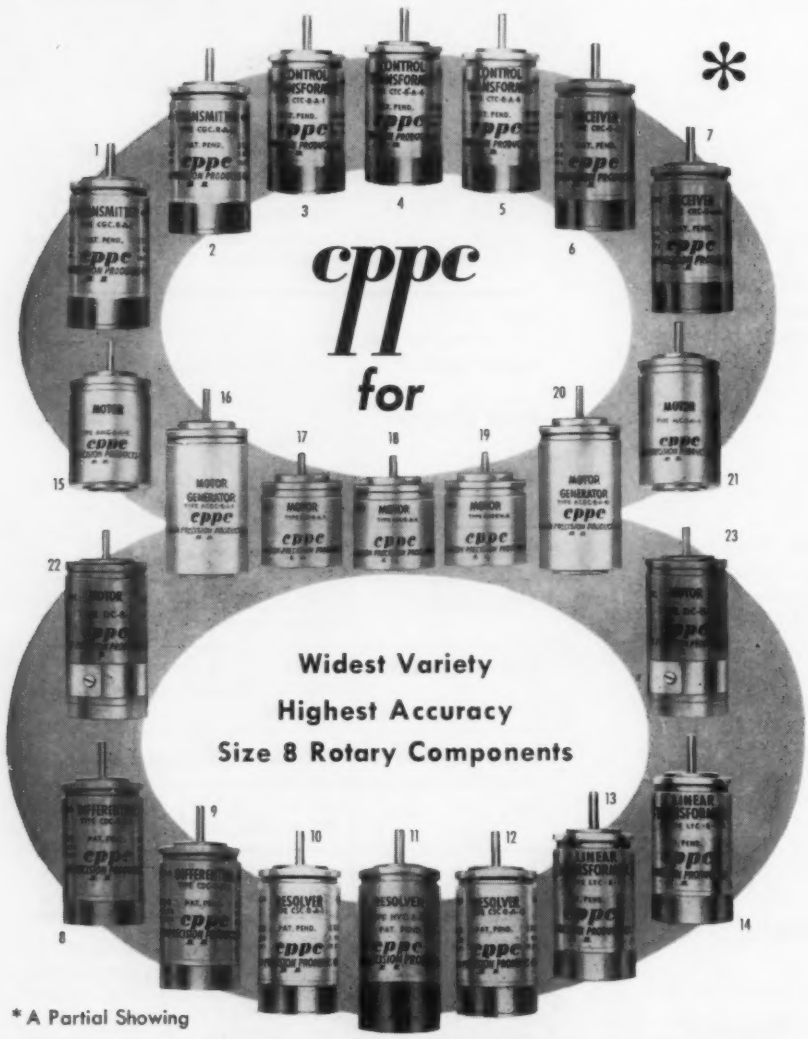

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Source: Moog Servocontrols, Inc.
East Aurora, New York
For Your Copy: Circle No. 142 on Inquiry Card.

Electronic Multiplier

16-page brochure describes an AM/FM electronic multiplier which provides dynamic accuracy of ±0.05% of full scale at 500 cps. The brochure includes general description, features and performance specifications of the system which provides four quadrant multiplication of input variables at frequencies in excess of that feasible by other methods. A complete discussion of theory of operation is provided, with another section devoted to a new type discriminator which provides an exactly linear relationship between AM and FM outputs. Interconnection diagrams show how the multiplier can be easily converted to perform division and square root functions.

Source: Computer Systems, Inc.
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Precision Switches

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Booklet contains engineering information, simple selection guides, illustrations and flow diagrams of many types of solenoid valves.

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Temperature Measurement and Control

23-page booklet discusses ways of putting temperature response to work, mercury-bulb instrumentation and nine basic types of controls. The engineering guide also provides basic concepts of electrical, pneumatic and mechanical controls. To illustrate instrumentation and what it can do, six brief case-histories are spotlighted.

Source: Partlow Corp.
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Servo Engineer's Handbook

128-page engineering textbook on servo components operation and the application of servomechanisms is extremely useful to designers of servo-systems. "The Servo Engineer's Handbook" deals with the use of individual components and although the basic theory is presented, the overall treatment is practical rather than classical. The author states that this is the first time that almost all practical servo component information has been assembled in a way that permits the designer to apply it immediately. Highlights of the 8 chapter book include: design methods and evaluation of servo systems; theory of operation, system design considerations and complete evaluation factors of servo motors, rate generators, synchros, gear trains and servo amplifiers. A chapter entitled, "Servo System Engineering" includes: system design procedure; mathematical evaluation of the servo loop design; frequency response method; open loop analysis; introducing system stability. Environmental testing procedures are also given in book. Price $3.00

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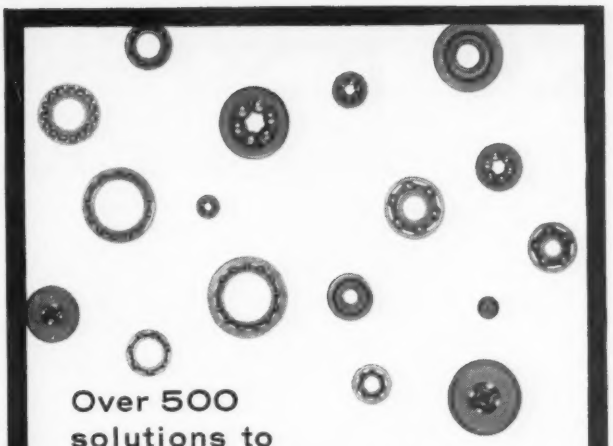

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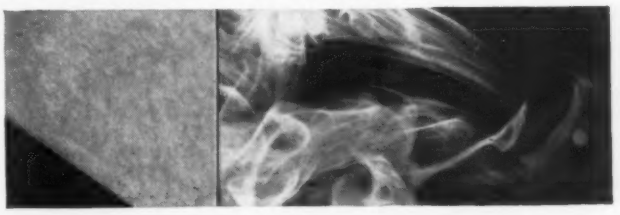

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Quick-Opening Fasteners

Selecting Small Fastenings for Metal Closures

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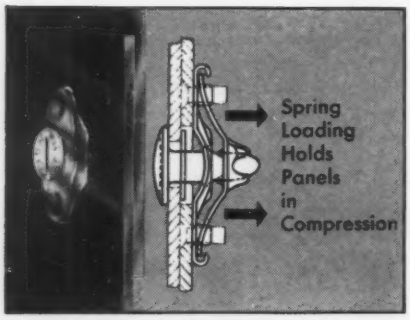
(John D. Folley, Jr. & James W. Altman, Research Scientists, American Institute for Research)



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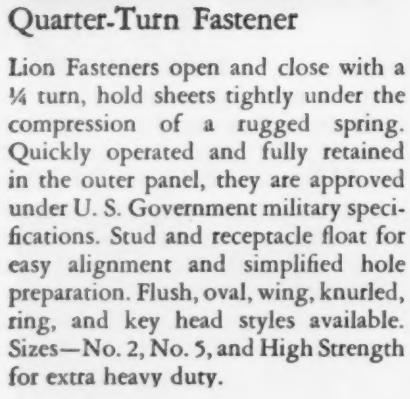

Cabinet Latch

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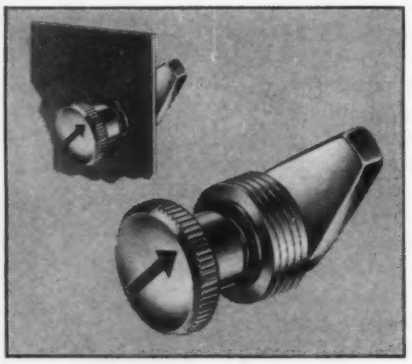
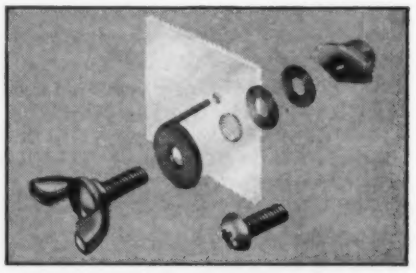


Spring Tension Latch

For fastening slide-out drawers and hinged panels the Southco Arrowhead Latch is recommended. It locks or opens with a quarter turn yet occupies less than ½" inside space.

Doors are held under spring tension—a push against the arrowhead knob relaxes this tension, allows operation with fingertip ease. Drill a single hole for installation—no fastening to the door is necessary. No striker plate is needed.

Pawl stop is eliminated—arrowhead shows at a glance exact position of pawl.



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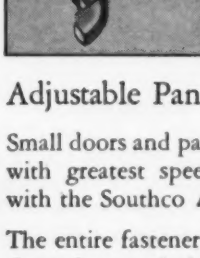

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* *Quotation from "Designing Electronic Equipment for Maintainability"; Machine Design, July 12, 1956.*

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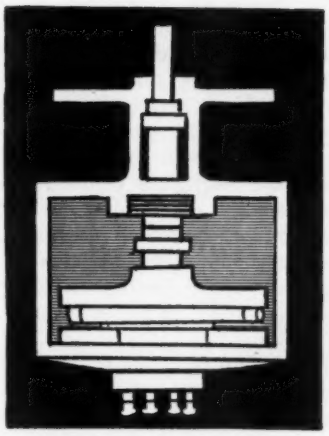


COMPONENTS 2 DIGEST

COMPONENTS DIGEST II, POTENTIOMETERS

Part II, High Temperature Potentiometers

Resistance potentiometers were described generally in Part I of this Components Digest, which appeared in our 1958 December Issue. Part II covers some problems and developments in potentiometers for high temperature applications. General design and material selection factors applicable to electromechanical components for high-temperature operation were considered in Components Digest No. 10. Many of the principles presented there are reconsidered here with specific reference to resistance potentiometers.

This presentation is not a complete survey, but rather a summary of information submitted by manufacturers in response to a questionnaire.

The first section reviews general design factors relating to high temperature performance. The second section describes a variety of commercial potentiometers suitable for operation between the temperature limits of 175°C and 260°C. The third section expands coverage to potentiometers operating above 300°C, including experimental varieties not yet available, and forecasts future developments.

Components designed to operate at elevated temperatures are usually characterized in terms of "maximum operating temperature". Bourns' engineers point out that this term has various connotations. One interpretation common in the components industry is the temperature at which power is derated, a second is the maximum temperature at which the component will operate within specifications on a short term emergency basis; a third is the maximum temperature at which the component will operate without failure over an extended period of time—1000 hours, for example.

Many of the materials used in the potentiometers on the market today, they say, withstand short-time operation at elevated temperatures, but are completely unsatisfactory for extended periods of time. Finding or developing materials that will operate satisfactorily for a long time, they say, is the major problem in high-temperature pot design.

They point out also that a distinction should be made between maximum operating ambient temperatures and maximum operating internal temperatures. Many pots described as 175°C units, for example, will not stand sustained exposure to 175°C ambients. The temperature designation often means that the internal components, such as the resistance element and contact materials, are designed to withstand 175°C for sustained periods of time.

Eugene Maurey, President of Maurey Instrument Corp., Chicago, Illinois says that choice of materials is the key to design of high-temperature electromechanical products. Relative expansion of materials with temperature must be carefully considered. Each of the materials used must withstand the desired temperature with an adequate factor of safety. The first material in a component to deteriorate with temperature rise, he says, is the major limiting factor in high-temperature performance of that component.

Table I is a list of materials suggested by Mr. Maurey as acceptable for use in design of pots for various temperature requirements. Undoubtedly, he says, other materials can be added to the list, but, as the table indicates, the number of available materials decreases as the temperature requirements increase.

TABLE I

Materials for High-Temperature Pots

To 125° C Some phenolics, Mylor, Teflon, ceramics, epoxy filled fibre glass, silicone resin fibre glass, most epoxy fillers, aluminum, bronze, brass, 303 stainless steel, all precious metals, stainless steel ball bearings, most enameled resistance wire, Mycalex, mica, phosphorus bronze, beryllium copper.

To 150° C Some phenolics and epoxies, fibre glass filled Teflon, mica, Mycalex, aluminum, brass, bronze, 303 stainless steel, ceramics, most bare resistance wire, high temperature solder, Saureisen cement, beryllium copper, cobalt-chrome-nickel alloy.

To 250° C Ceramics, mica, Mycalex, welded joints, 303 stainless steel, dry molybdenum disulfide, Saureisen cement, some resistance wires, glass, cobalt-chrome-nickel alloy.

To 350° C Alumina ceramics, mica, Mycalex, a few resistance wires, Saureisen cement, glass, cobalt-chrome-nickel alloy.

COMPONENTS DIGEST

In the following paragraphs Mr. Maurey discusses briefly some of the factors that must be given detailed consideration in high-temperature pot design.

- *Bearings.* Particular emphasis must be given to bearing design. Even stainless steel bearings tend to corrode and become welded in place or excessively worn in but a short time at elevated temperatures. The possibility of using ceramic bearings is being considered.

- *Sealing.* At elevated temperatures, sealing the unit at the shaft end is practically impossible. This is primarily due to the unavailability of a high-temperature flexible material to act as a seal. Also, the difference in the coefficient of expansion of adjacent materials makes sealing difficult. Fortunately, the environment is often dry at high temperatures, so that sealing the potentiometer is unnecessary.

- *Temperature Coefficients.* Relative expansion of materials in close proximity to one another at elevated temperatures must be carefully considered. A strong mechanical joint of two materials with unlike temperature coefficients frequently results in a loose joint after it is once subjected to a temperature cycle. Brazing of metals to compatible ceramics is good practice. Mechanically joined materials with similar temperature coefficients and welded joints are acceptable connections. Electrical connections must be mechanically as well as electrically joined.

- *Contacts.* The number of sliding contacts on a potentiometer should be reduced to the minimum. If possible, a pigtail or equivalent arrangement should be used rather than a conventional wiper on the collector ring.

- *Spring Material.* Few acceptable materials retain their spring quality at elevated temperatures. One of the best is an alloy of cobalt-chrome-nickel which is useful to 400°C. This material resembles a hard stainless steel but can be welded and formed.

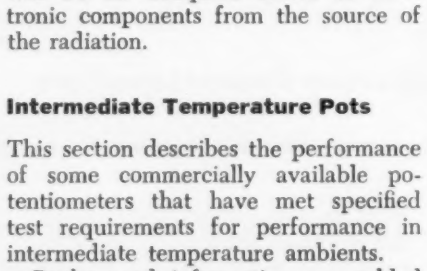
- *Winding Element.* Perhaps the greatest single stumbling block in high temperature potentiometer design, Maurey says, is the winding element. He quotes David Lawton, of Technology Instrument Corp., as saying, "If you can make a good winding, you can make a good pot!" Maurey adds that this is equally true in high-temperature potentiometer design. The most acceptable mandrel materials, Maurey says are ceramics of a high tensile and compressive strength.

Another limiting factor in design of high-temperature potentiometers, Maurey points out, is that they may be required to withstand the effects of radiation. This requirement presents additional problems in design, because it further limits the number of materials that can be used. Frequently, a material that is acceptable for a high-temperature is particularly susceptible to radiation. Such is true for cobalt alloyed metals. Some materials that resist radiation, corrode at high temperatures. Perhaps the final answer to the problems of radiation, he says, will be an adequate shield of electronic components from the source of the radiation.

Intermediate Temperature Pots

This section describes the performance of some commercially available potentiometers that have met specified test requirements for performance in intermediate temperature ambients.

Background information on molded conductive plastic potentiometers is also included because this type of unit was overlooked in Part I and because conductive plastic elements are inherently suited to intermediate temperature operation.



Conductive Plastic element

CONDUCTIVE PLASTIC POTS

Element. Markite molded resistive elements embody a hard, smooth, conductive plastic, which can be provided in a wide range of electrical characteristics. The element consists of a solid track of conductive plastic integrally co-molded with terminals and taps to a rigid supporting structure of a mineral-filled phenolic non-conductive plastic which has a matched thermal expansion coefficient. Figure 1 illustrates a typical plastic element configuration. The conductive track is approximately 0.030 x 0.040 inches in cross section in standard units, but the area can be varied to meet specific requirements. The extremely low coefficient of friction of the element permits unusually high wiper forces which result in excellent shock and vibration characteristics while maintaining low torque. Markite potentiometers have withstood vibrations to 70g at 5 to 2000 cps and shock loads of 100g without malfunction.

Terminals and Taps. The integrally molded terminals and taps form a permanent part of the resistive track at the point of their intersection with the resistance element and cannot be shaken or vibrated loose. Tap width is not significant electrically since the tap intersects the element track below the wiper contact surface. Thus, shorted areas normally found at tap locations are eliminated and continuous, essentially infinite, resolution is maintained.

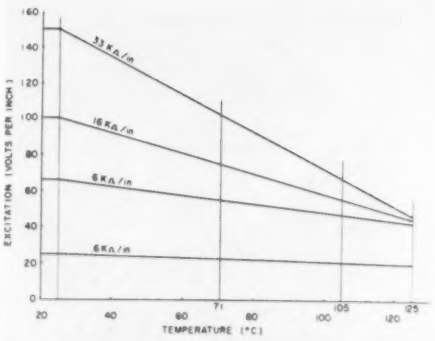
Mechanical terminal and tap positions are located within machining tolerance in the molding dies. Duplication, from prototype to production, and from element to element is assured since each unit is an exact mirror reproduction of the die. Electrical tap locations can be controlled to tolerances far closer than normal linearity bands.

Contacts. Controlled, heat-treated, beryllium-copper cantilever springs with precious metal contacts are used for the wiper and take-off system.

Noise. In any type of potentiometer there are three major types of noise: mechanical, electrical, and triboelectric. If it were possible to detect wiper voltage with a truly infinite impedance measuring device, both mechanical and electrical noise would be non-existent in the voltage output of a Markite pot. Mechanical noise results from spurious motions of the wiper caused by externally applied shock and vibration, which varies contact resistance and causes minute high frequency output variations. Ability of conductive plastic units to use high brush forces generally reduces this component of noise to an insignificant factor.

Electrical noise in a conductive plastic potentiometer is a repeatable variation of contact resistance caused by micrononlinearities in the element and is independent of wiper velocity. Since this component of noise appears in use-circuits as a variable resistance in the wiper circuit, it is not significant under conditions where the pot is feeding into moderately high impedances. Electrical noise often improves with "wearing-in" of the element and wiper combination. This occurs because a wiper bearing area is produced which tends to average out minute linearity variations.

Triboelectric noise is a self-generated EMF which occurs when two different materials are rubbed together.



Excitation voltage rating vs. temperature ambient of standard conductive plastic elements

The low co-efficient of friction between the conductive plastic element and the wiper results in a triboelectric component that is in the order of microvolts and can therefore be considered negligible.

Noise in a conductive plastic potentiometer is substantially independent of operational life. Life test noise traces actually exhibit a substantial reduction in noise over more than 90% of the electrical travel during the first 30 million revolutions.

Resolution. The resolution of Markite Potentiometers is virtually infinite. Tests have shown that the resolution is better than 40 millionths of an inch, which represents the limit of the test equipment.

Linearity. Linearities of ±0.05% are available on single turn 1-5/16 inch diameter units and ±0.01% linearity is available on single-turn, 5-inch units. These linearities are not significantly affected by temperature, or humidity variations.

Power Dissipation. It is customary to specify power dissipation capacity of potentiometers in terms of wattage vs ambient temperature. Wattage is then converted to applied voltage vs ambient temperature. Since voltage is the desired parameter derived from the power dissipation curve, and since voltage gives a more realistic measure of potentiometer performance (it is independent of resistance changes), power dissipation is often presented as a series of voltage curves vs ambient temperature for specific element resistances.

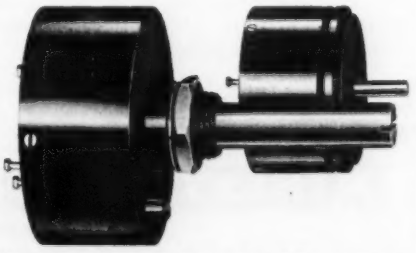
The above figure is a plot of applied voltage per linear inch of resistance element vs ambient temperatures for specific element resistances. The curves indicate excitation voltages safely withstood by elements for a minimum of 500 hours. Higher temperatures or voltages are possible for shorter periods of time. Immersing the element in clean oil improves heat dissipation and increases the wattage rating by a factor of two in most cases.

The capacity of Markite potentiometers to withstand high temperatures is a function of the duty cycle at the high temperature and the degree of degradation that can be tolerated. Units have withstood 290C ambient temperatures and have exhibited satisfactory performance characteristics.

Markite says they did not design their standard pots to operate at 200 to 250C; satisfactory applications of units in this temperature range resulted in large part due to the inherent thermal resistance of the conductive plastic element. Essentially all they needed to do for these applications was to substitute 95-5-10 antimony composition for soft solder and to gold plate the silver parts, because silver has a tendency to oxidize at higher temperatures.

All electrical contacts are mechanically and electrically joined so the contact will be secure under extreme conditions of temperature and vibration.

In one application of a Markite pot at these temperatures, a 20-64 rectilinear unit was modified as described above for short term operation in hydraulic fluid at 260C. To evaluate the instrument for this application several Type 2064 rectilinear pots were tested immersed in OS-45-1 hydraulic fluid under static and dynamic conditions for periods of from 1 to 3 hours. A summary of the results showed that



Markite type 2094 and 3033 potentiometer

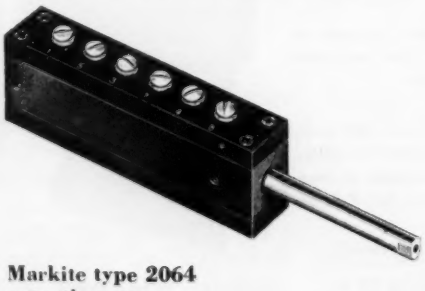
operation of the potentiometer appeared satisfactory during all tests.

The good results of these tests prompted Markite to run more extensive tests of their own. For these tests they used their standard 2094 rotary units. Again, the only modifications in the units were that the solder was changed and the silver parts were gold plated. First they conducted rotational and static life tests at 200C with no load on the units. Nine units under static conditions and four units run at 120 rpm were tested for a period of 1000 hours. The purpose of the test was to determine the suitability of the conductive plastic element for operation at 200C. It was found that average linearity of the four rotational samples was virtually unchanged as was noise level and contact resistance.

Bourn Model 113 potentiometer

Bourns new high temperature linear motion potentiometer, Model 113, designed to operate at temperatures up to 260°C will give precision electrical indication of mechanical position when used with hydraulic actuators, pneumatic valves and linkage components. The instrument operates with a high level ac or dc signal, requiring no amplification for use in recording, control and telemetering circuits.

High temperature operation is made more reliable by the incorporation of Bourns' exclusive Silverweld resistance element termination. In this design, a broad band of metal is fused directly to the resistance element. The external terminals are then fused directly to



Markite type 2064 potentiometer

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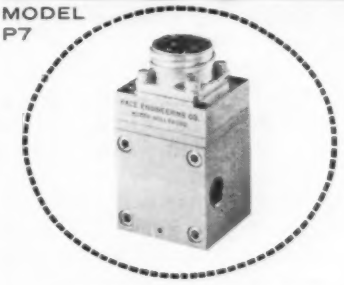
MODEL P7



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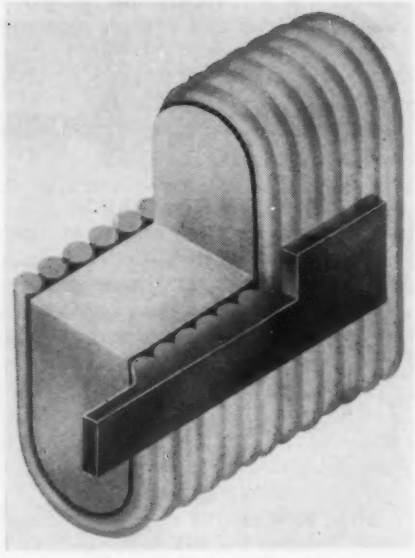
COMPONENTS DIGEST



Bourns Silverweld* Termination

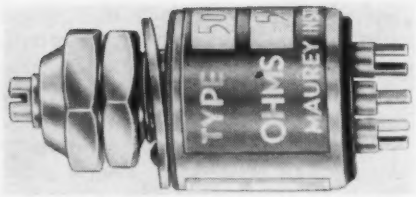
*trademark

this band. Fusion provides a continuous electrical circuit from one external termination through the resistance element to the other external terminal, rather than just a mechanical connection. Some of the advantages of this new termination technique, Bourns says, are:

- It works extremely well with the hard Nickel-Chrome alloys, providing a secure bond that cannot be broken without actual destruction of the element itself.
- Unitized element construction eliminates the danger inherent in drawing one strand of resistance wire away from the body of the element.
- It may be used with ceramic cards to provide a resistance element of extremely high temperature capabilities. Elements of this type have been tested to over 500°C and have also been temperature cycled from room temperature to 230°C without failure.
- Its mechanical strength is extremely high and it is virtually unaffected by vibration or shock.

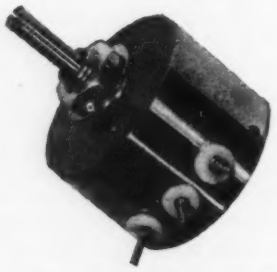
In addition, the element is manufactured with low temperature coefficient resistance wire and ceramic mandrel for excellent stability at extreme temperatures.

The body of the potentiometer is made of stainless steel to resist corrosion. The bearings are made of a sintered material with a special high temperature oil added. The block that

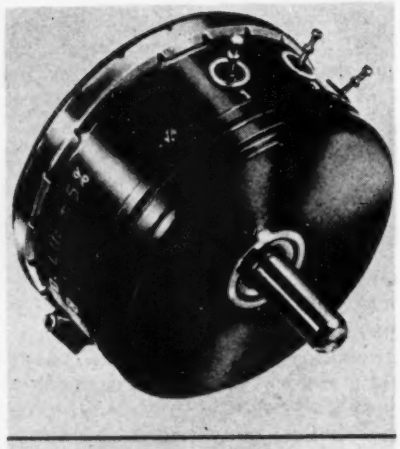


***Maurey 50-M14*—1/2 diameter Trimmer potentiometer; resistance range 25 ohms; ambient temperature range of −55° to +175C; power rating of .5 watt at 150C derated to 0 at 175C. Toroidal wound mandrel and stainless steel housing with mica and ceramic insulation.**

***Helipot "Helitrim"*—1¼ long trimmer potentiometer; conductive glass resistance element; resistance range: 500 to 20,000 ohms; ambient temperature range: −55° to 200C; power rating 1.5 watts at 120C derating to 0 at 200C.**



***Waters Type HT-1*—"*Hotpot*"—1" diameter single turn precision potentiometer; ambient temperature range of −55° to +225C; power rating 1 watt at 200C, derated to 0 at 225C. Nichrome resistance element wound on a ceramic toroidal mandrel.**



***Technology Instrument Corp. HHF-2*—2" diameter single turn servo precision potentiometer. Resistance range 500 to 50K ohms; ambient temperature range −65° to +225C; power rating 2 watts at 75C derated to zero at 225C. Hermetic sealed, metalic film, resistance element.**

Daystrom Pacific Series 314 potentiometer.

MINIATURE WELDERS

WELDING HEAD WHD 4A

Bench welding head with foot or air operation Pressure 1 to 20 lbs. Precise, linear, motion. Stroke 2". Easy to set up and to jig up.

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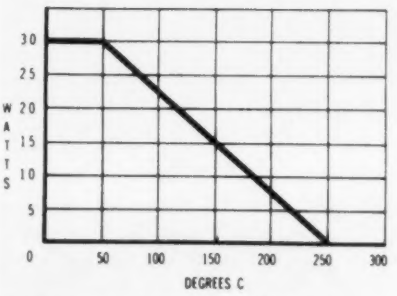


Power rating of Daystrom 314 pot

holds the resistance element is a formica fibre glass laminate which has a maximum operating temperature of about 300°C. All internal joints that require strength are brazed with noble metal or spot welded. Potting compounds are silicone adhesives made by Dow Corning. Wiper springs are stainless steel. Power rating of the unit is 4.0 watts at 40°C derated to 0.1 watt at 260°C. Vibration level without electrical discontinuity or error greater than ½% is 15G, 20-2000 cycles.

Model 113 is designed to meet or exceed most government specifications. Many special features, including center-taps, variable mounting, shaft connectors, turret terminals and other custom styled features can be incorporated in this new model.

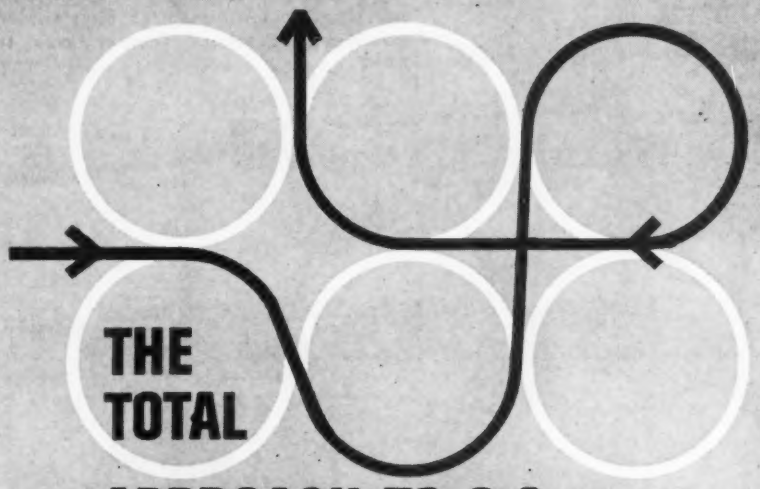
Daystrom Pacific Series 314 subminiature high-temperature potentiometers meet requirements of applications where temperatures to 250°C are encountered and space is at a premium. Only ½ inch in diameter and weighing 10 grams these single-turn, wire-wound units are available in resistance values from 10 ohms to 50K, in servo, panel, or panel with shaft lock mountings. Best practical linearity is 0.5%.

Three of these units, load-life tested at 215°C for 1000 hours with 0.5 watt power applied, met or exceeded specifications Jan-R-19 (7), Paragraph F-3i and MIL-R-19A, Paragraph 4.6.8. Power was applied in cycles of 1½ hours on and ½ hour off over the 1000 hour period. Before testing, resistance, noise and insulation resistance were measured. After 1000 hours under temperature and load the maximum change in resistance was 1.95%, equivalent noise resistance had increased to only 10 ohms which is 1/10 that allowed in the specs, and insulation resistance remained in excess of 100 megohms.

300 To 500° C Pots

A good way to determine what the next generation of pots will be like is to find out what kind of temperatures and performance the Military is specifying in their research and development contracts. The answer is contained in a specification for "Ultra-High Temperature Radiation Resistant, Precision,

quality control engineers



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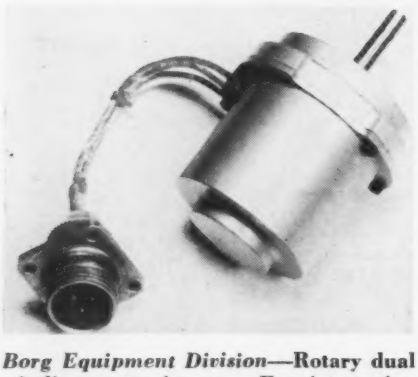
COMPONENTS DIGEST

Borg Equipment Division—Rectilinear precision potentiometers. For guided missile application. Temperatures to 300F.

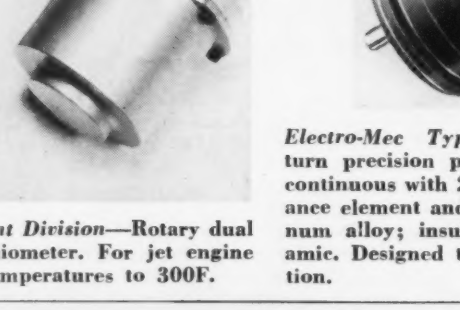


Borg Equipment Division—Rotary dual winding potentiometer. For jet engine application. Temperatures to 300F.

Electro-Mec Type 11 PS-GI—Single turn precision potentiometer, operates continuous with 2 watts at 343C. Resistance element and slip rings are a platinum alloy; insulating material is ceramic. Designed to resist nuclear radiation.

Maurey Type 200-M27—2" diameter precision potentiometer; resistance range 250 to 100K ohms; ambient temperature range —55C to 325C; power rating of 4 watts at 300C, derated to 0 at 325C. All ceramic housing, bearing and shaft. Wire-wound resistance element on a ceramic toridal mandrel. Highly resistant to nuclear radiation.

FREEDOM



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LITTON INDUSTRIES Electronic Equipments Division
Beverly Hills, California

Potentiometers" written by the Wright Air Development Center.

The Air Force is looking for potentiometers that will do everything other pots do and also operate under 2 watts of load at 500°C. Resistance change is to be no more than 5%, noise is not to exceed 500 ohms, linearity must be ½% for precision units and 1% for standard units. In addition to these high-temperature requirements, the units must operate satisfactorily at —55°C and at 95% humidity, they must withstand accelerations of 10G, and they must be radiation resistant.

A major problem in design of potentiometers for very high temperature applications mentioned by Bourn's Application Engineers is volitization of the enclosure material, potting materials or cements which can coat the surface of the resistance element and the contact spring causing noise to the extent of an erratic output.

Another problem, they point out, is that of sealing units required to resist effects of humidity at low temperatures following exposure of the units to high temperatures. Of course many high temperature applications in missiles are one-shot operations where the only humidity requirements are those that have to be met on the ground. Sealing against humidity in such cases is not so difficult.

George Brown, Director of Engineering at Bourns, Inc., says that when you get into the 300 to 500°C region, even high temperature materials such as silicones and Teflon are not satisfactory; flexible materials, in general, are left behind. You are forced into designs that are practically all metal and ceramic. Even wire insulation has to be ceramic. Wiper contacts become especially critical as temperature increases. Noble metals are a requirement to avoid the danger of oxidation or surface contamination at these elevated temperatures.

A good principle to keep in mind in evaluating high temperature pots, Brown says, is that the higher the temperature the more important it is to keep the number of elements small and the design of these elements simple to avoid the accumulation of gross errors and friction problems as a result of temperature expansion.

An approach to the high-temperature problem that should not be overlooked, Brown suggests, is water cooling or air cooling the instrument. This technique is often used, he says, for small units where water or cooling air is available. In some cases where rocket engine exhaust pressures were to be measured, engineers have used this technique to keep the measuring instrument at a reasonable working temperature.

In spite of the difficulties presented, however, Brown believes that no critically new break through in the current state-of-the-art is required in the development of 500°C pots; suitable materials and techniques now exist.

It must be admitted, he says, that performance at these temperatures is not as good as at normal room temperature but it is not sufficiently different to warrant developing entirely new instrument designs or new instrument approaches.

Bourns reports that they have developed a prototype model of a wirewound potentiometer that operates successfully in excess of 350°C. Approximately 3 years of research have been spent on this development. They expect to have production models of this design available in a few months.

Commenting on future trends, Bourns predicts that a large percentage of their developments in the very high temperature pot. field will use film-type elements. They say that metal oxide, glass and vacuum deposited films seem to have high stability power rating under high temperatures.

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CIRCLE 58 ON INQUIRY CARD

Continued from Page 82 of December 1959 Issue

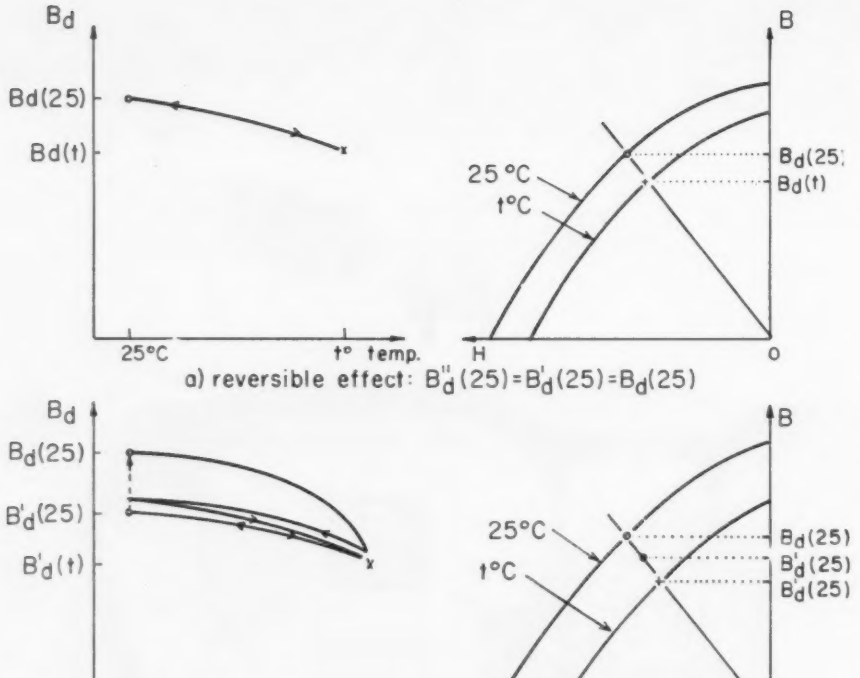

Fig. 17—Schematic diagrams showing the effects of temperature on remanence.

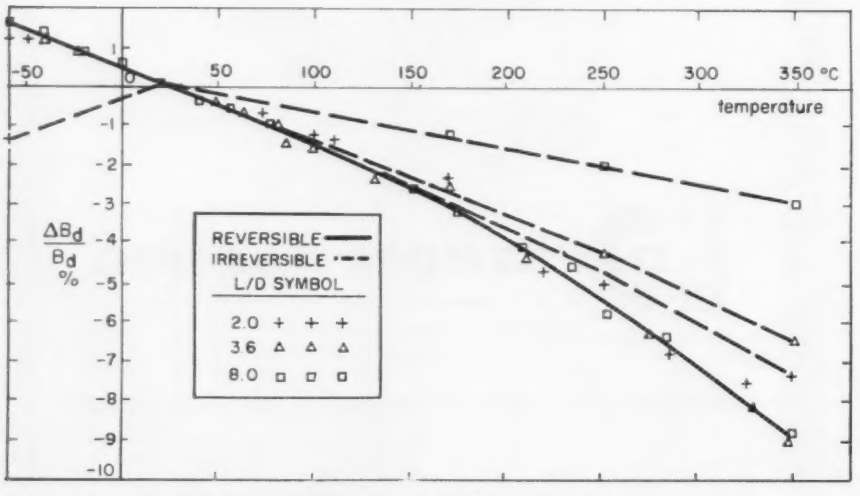

Fig. 18—Variations in remanence of Alnico 2 due to temperature.

Materials and Techniques for

High Temperatu ompon

Permanent Magnets

Some modern applications require that permanent magnets operate at rather high temperatures (often above 300°C). The question whether magnets perform satisfactorily at such temperatures can be answered affirmatively for most common commercial magnet materials of the present.

The various effects of temperature on the remanent induction of magnets can be classified as:
(a) reversible effect
(b) irreversible effect
(c) material effect

These effects are illustrated in the schematic diagrams of Fig. 17. Remanent induction (B_d) usually decreases as temperature is increased. For small temperature ranges this decrease can be entirely reversible (see diagram of Fig 17a). The original value of remanent induction is regained upon return to room temperature (25°C).

For wider temperature ranges, an irreversible loss of remanence is likely to occur in addition to the reversible change; i.e. upon return to room tem-

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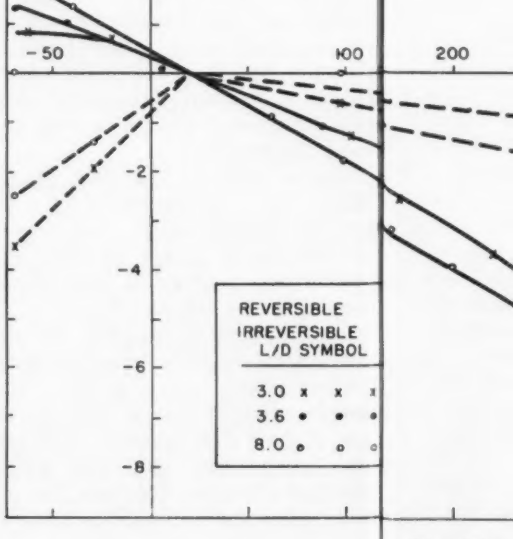

Fig. 21a—
Alnico 5

Information in this section is based on work performed by the Indiana Steel Products Co., under sponsorship of the U. S. A. F. Wright Air Development Center.

omponents

perature the remanent induction, $B_d'(25)$, is below the original value $B_d(25)$. This loss can be regained by re-magnetization.

At even higher temperatures, the material can change. This change in turn influences the hysteresis loop and remanent induction. Changes in the material may result in lowering or in raising the remanent induction. The original value $B_d(25)$ cannot be regained by re-magnetization. In diagram c of Fig. 17, re-magnetization yields $B''_d(25)$.

At high temperatures, the three effects are likely to occur together. However, there are means to minimize or nullify the irreversible loss and the material effect prior to the application of the magnets.

Irreversible losses usually occur only during the first three temperature cycles, the changes of remanent induction becoming smaller in each cycle. Thus, magnets can be stabilized for a certain temperature range through at least three exposures to the extreme

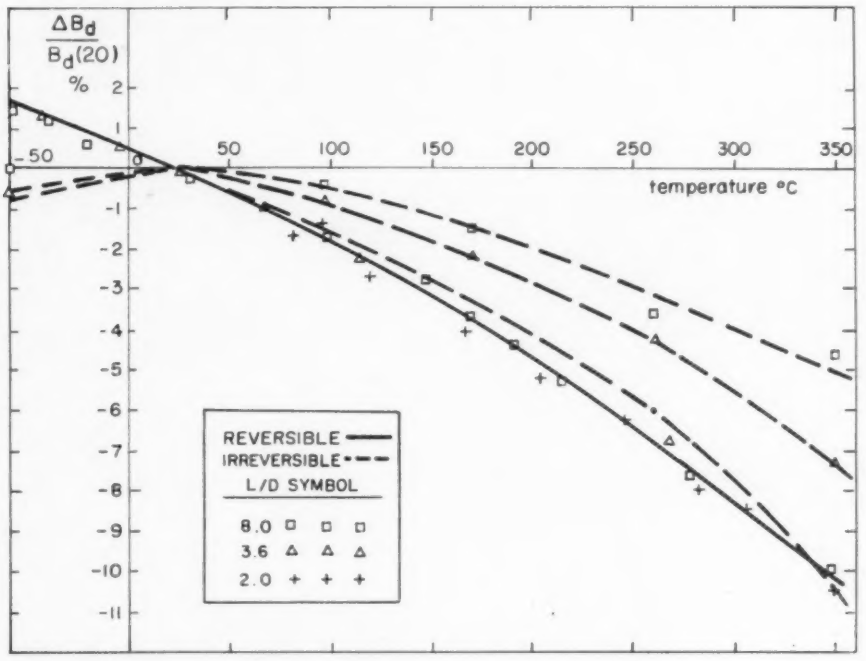

Fig. 19—Variations in remanence of Alnico B due to temperature.

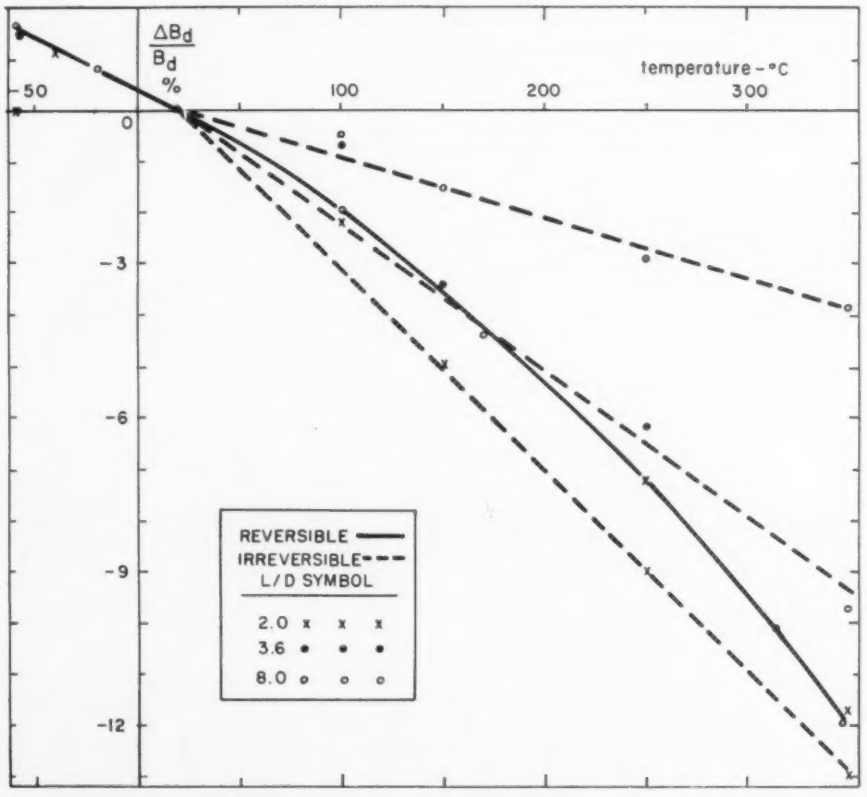

Fig. 20—Variation in remanence of Alnico 4 due to temperature.

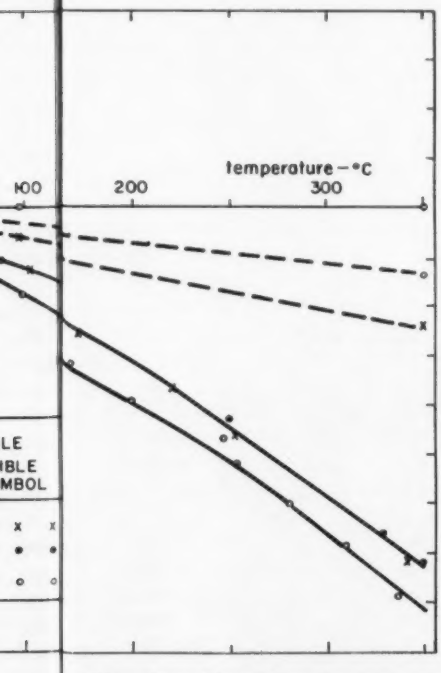

Fig. 21a—Variations in remanence of Alnico 5 due to temperature.

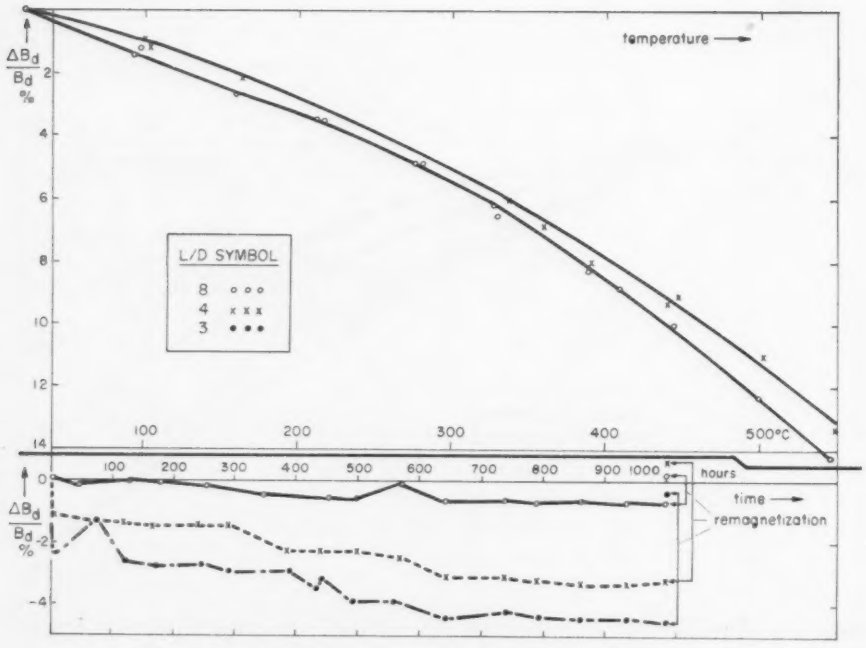

Fig. 21b (top)—Reversible changes of remanence of Alnico 5 with temperature. (after 1000 hours at 548C). (bottom) Changes of remanence in Alnico 5 at 548C.

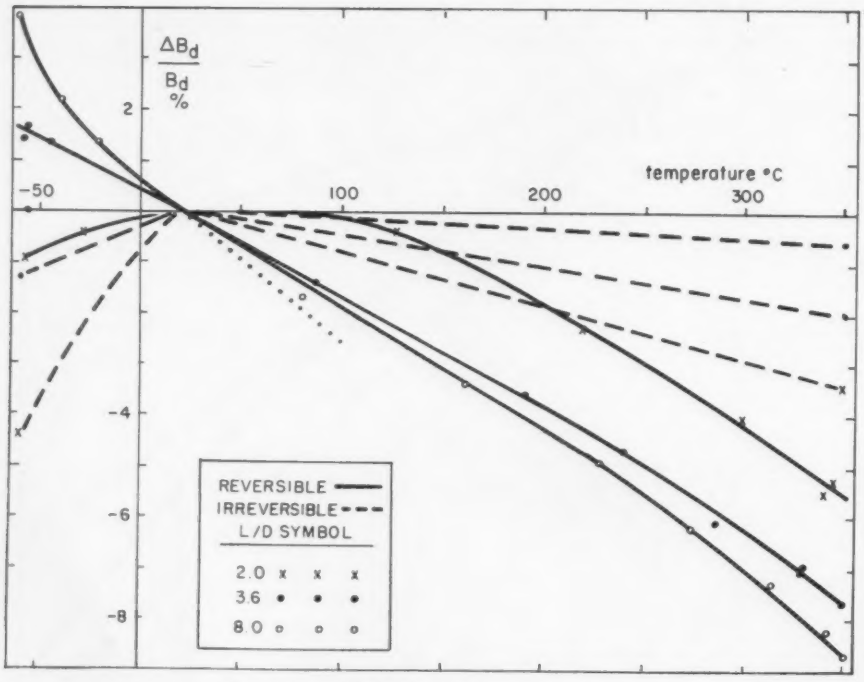

Fig. 22a—Variations in remanence of Alnico 6 due to temperature.

temperatures of this range. On the other hand, the common a-c stabilization can be used also to stabilize magnets against irreversible losses due to temperature. However, to secure stability, the "a-c knock-down" of remanence has to be at least twice as great as the irreversible loss which would result from temperature cycling.

The material effect is rather different for various materials. Ceramic magnets have no material effect in their useful temperature range. The material of Alnico V and VI magnets after the technical heat treatments is fairly stable up to 550°C. Changes in remanent induction due to changes in the Alnico V and VI material usually do not exceed ±3% of the value at room temperature. These changes can be reduced to less than ±1% by proper heat treatments. Other Alnico alloys are also fairly stable in this temperature range; however, the remanent induction of Alnico II, III, and IV magnets is lowered considerably through irreversible losses and the reversible changes.

When magnets are properly heat treated and stabilized against irreversible losses, their remanent induction still changes reversibly according to the solid curves of the diagrams in Figs. 18 to 23. These diagrams contain also the irreversible losses measured at room temperature after stabilization at the temperatures indicated by the dashed lines.

Note in these diagrams the following facts:

- The dashed lines show that irreversible losses are the greater the smaller the length to diameter ratios (L/D) of the magnets. This means that magnets operating in the lower portion of the demagnetization curve have greater irreversible losses than the ones operating in the higher portion.
- Figures 21a, b and 22a, b show that the reversible changes can depend on the L/D of the magnets. Moreover, comparison of Figures 21a with 21b and 22a with 22b shows that heat treatment influences the reversible effects. Therefore, it seems advisable in critical applications to discuss the temperature effects with the magnet manufacturer. This advice also holds for applications of magnets at temperatures beyond 550°C.

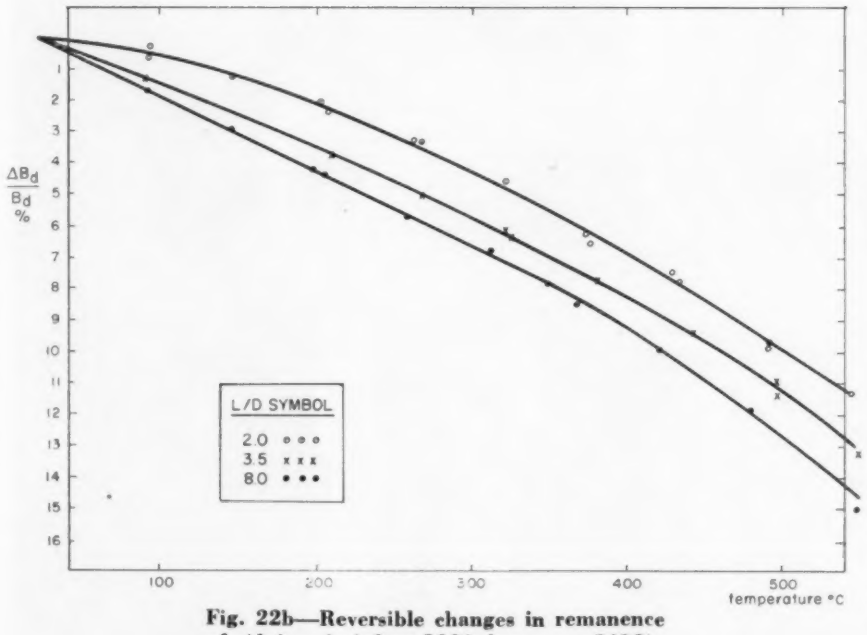

Fig. 22b—Reversible changes in remanence of Alnico 6 (after 1000 hours at 548C).

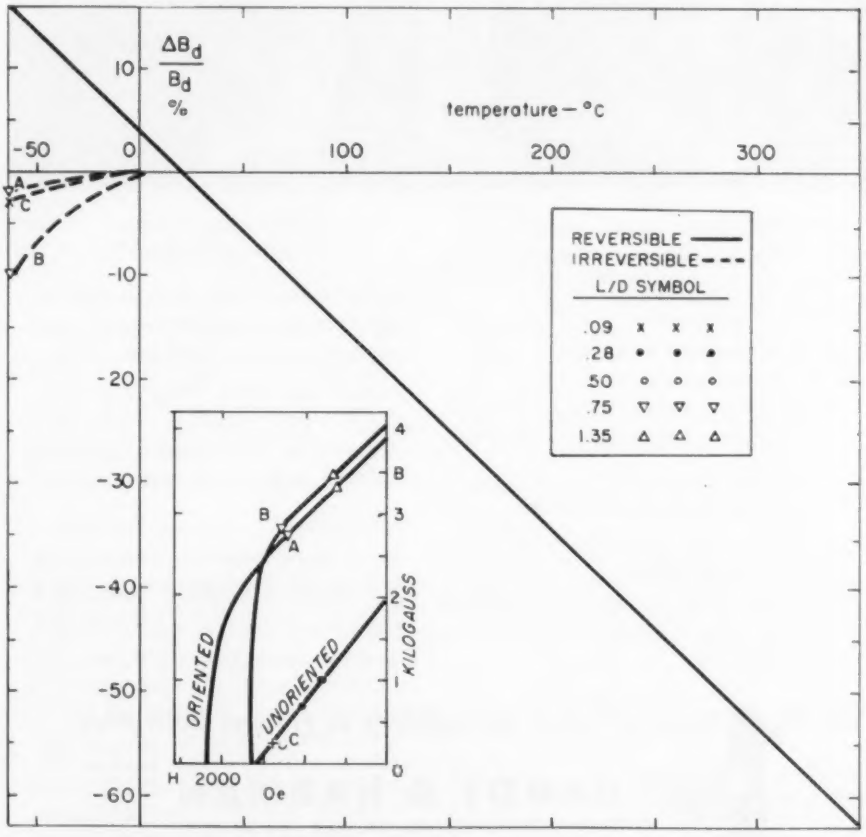

Fig. 23—Variations of remanence of barium ferrite due to temperature.

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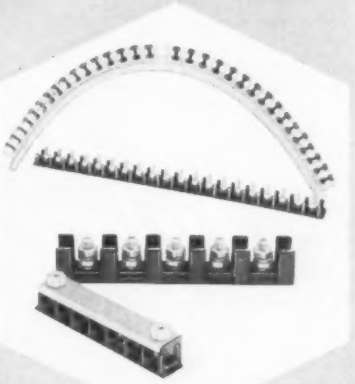

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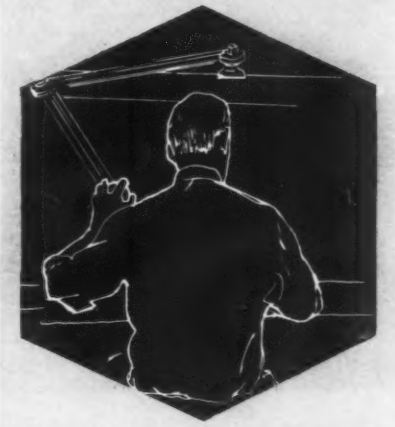

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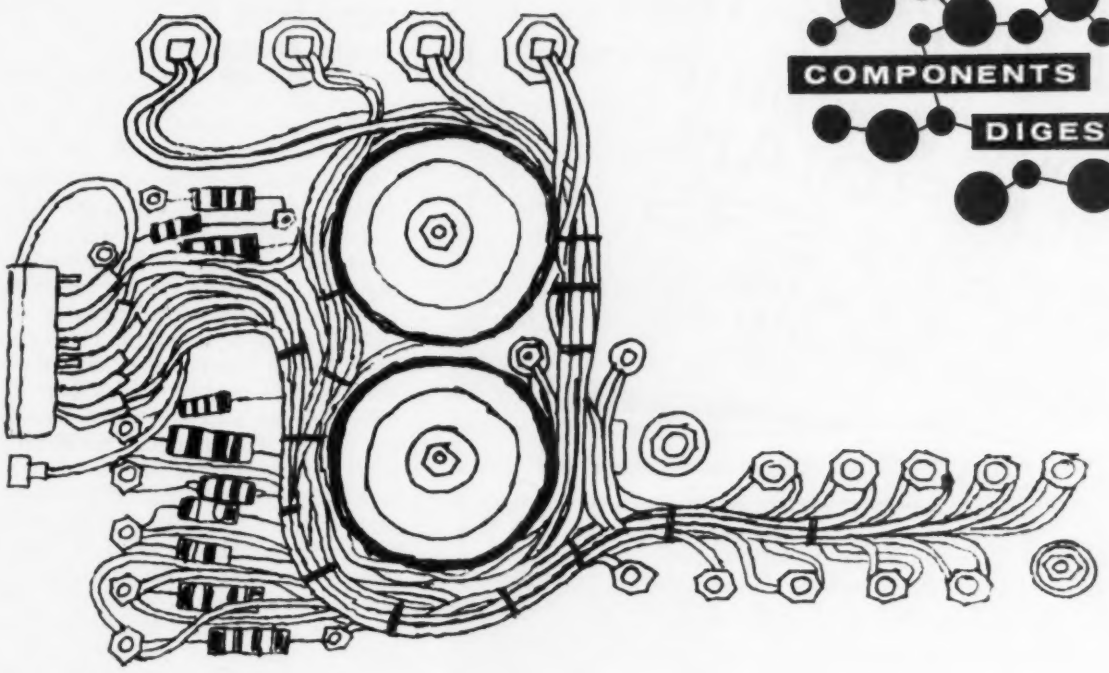


COMPONENTS DIGEST II

Audio Amplifiers PART ONE

Introduction

In the terminology of the electromechanical engineer an audio amplifier means any device that amplifies signals whose frequencies range from 20 cycles/sec. to 20,000 cycles/sec. This definition covers a host of very different amplifiers. On the basis of usage, three major categories can be described:

A-C Control. Amplifiers used in a-c control account for a larger portion of the commercial market. These amplifiers must produce an amplitude modulated signal to drive a control motor. We can therefore include thyratron, magnetic, vacuum tube, and transistor amplifiers in this category. Large harmonic distortion in the output wave shape can be accepted.

Harmonic Generators. Amplifiers in this category are used to drive harmonic generators such as speakers, shakers, or vibration tables. These amplifiers are expected to produce clean, high power signals.

Instrumentation. This type of amplifier would be used to drive recorders, instruments, and small servo motors. The general characteristics of these amplfiers are low noise, low harmonic distortion, and low power.

This Components Digest will consider all three categories of amplifying devices. The introduction, Part I, is general discussion of the different principles of amplifier operation and their relative advantages and disadvantages. Part II, in this issue is a detailed discussion of transistor amplifiers. The discussion is limited to the most fundamental design factors and does not take into account the multitude of sophisticated variations developed for biasing, power output, coupling, etc., or the many variations in transistors. Future sections will ocver such devices as magnetic amplifiers, vacuum tube amplifiers, and thyratron amplifiers

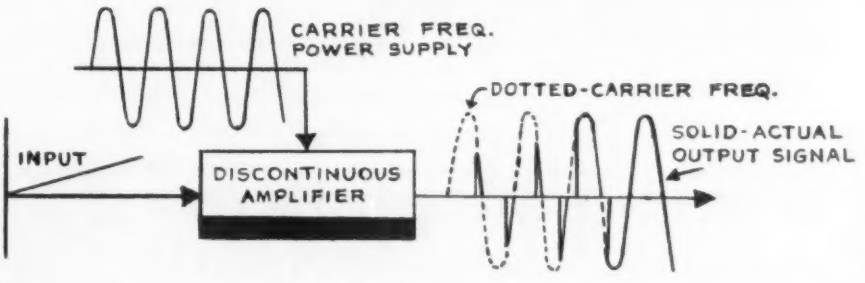
The object of the Digest is to give the electromechanical engineer the information he needs to evaluate and select packaged audio amplifiers.

CONTINUOUS AND DISCONTINUOUS AMPLIFIERS

To achieve our purpose, we will distinguish between two types of amplifiers, continuous and discontinuous. Continuous amplifiers try to reproduce the input wave form exactly. Transistor amplifiers and vacuum tube amplfiers fit into this category. Discontinuous amplifiers, on the other hand, try to reproduce the input wave form on some average basis. Magnetic amplifiers and thyratron amplifiers fit into this second category.

Discontinuous amplifiers could be more exactly described as having a common "thyratron" action. The term "thyratron" is derived from the Greek word $\theta\nu\rho\alpha$ which means gate or door. Discontinuous amplifiers, in other words, gate or switch power into the load as a functon of the input signal.

Audio amplifiers of this type are usually used to produce amplitude modulated signals. The envelope of the modulated signal contains the information and is a rectified average of the actual signal. In this way the averaging process inherent in discontinuous



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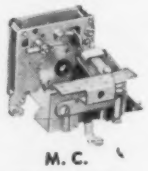

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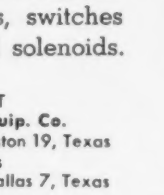

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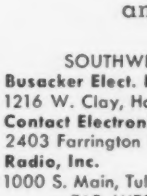

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COMPONENTS DIGEST

quency power is applied to the device and the amplifier action is achieved by synchronous gating of the power into the load. The point during the carrier cycle at which gating occurs is controlled by the input signal. This operation can be described by the sketch below which shows a ramp input to a discontinuous amplifier and the resulting output. The output is made up of parts of the carrier frequency wave supplied to the amplifier. If the output were rectified and averaged, the resulting signal would be similar in form to that of the input. In the sketch the input was d-c, but discontinuous amplifiers can be designed to accept amplitude modulated or pulsed signals. A more detailed discussion on discontinuous amplifiers will be presented in a future section of this Digest.

MAGNETIC AND THYRATRON AMPLIFIERS

So far, we have said that continuous amplifiers can reproduce any input audio signal, whereas discontinuous amplifiers are limited to production of amplitude modulated signals. Of course, as the carrier frequency increases, the discontinuous output takes on the appearance of a continuous signal. The carrier frequency is limited in the thyratron mainly by the ionization time and in the magnetic amplifier mainly by the eddy current losses in the cores. Historically, however, magnetic and thyratron amplifiers have been used primarily for the high power amplitude modulated signals required by a-c control motors and other electromechanical devices (also for r-f modulation and d-c). Recently, more applications have been found for these amplifiers at lower power. Magnetic amplifiers have been especially favored because of their ruggedness and long life.

Probably the worst drawback to using either magnetic or thyratron amplifiers for even modulated signals is their inherent dead time. Both devices amplify by resetting either the thyratron or the saturable reactor during the off-half cycle. This is one reason why large power gains are available; control power is applied only when the device is off. This type of operation, however, means that to effect the output, we have to wait a half cycle until the reset device turns on again. This half cycle dead time is

a minimum; most designs will produce closer to a cycle or more. Normal electrical delays must also be considered, but maximum bandwidth can be estimated from dead time alone. For example, if a one-cycle dead time occurs, the maximum bandwidth is about 7.5 cycles/sec. for a 60 cycle/sec. carrier system and about 50 cycles/sec. for a 400 cycle/sec. carrier system. (Bandwidth is measured from the zero envelope frequency to the envelope frequency at which 45 degrees of phase lag is experienced.)

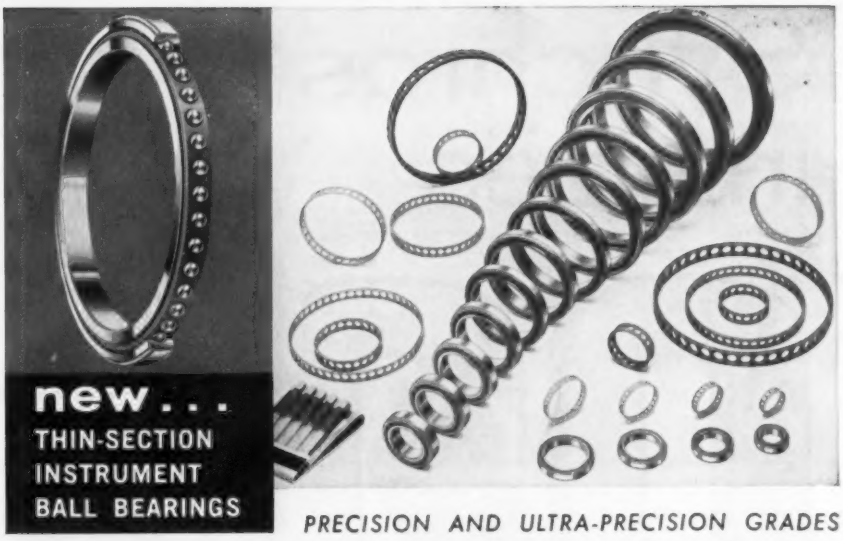
At 400 cycles/sec., these amplifiers can be applied in some of the most demanding applications. The size and weight of thyratron and magnetic amplifiers are comparable to that of vacuum tube amplifiers, but discontinuous devices can be much more efficient since they have little power loss when "on". Thyratron amplifiers are especially insensitive to the magnitude of the load impedance. Any resistive load can be driven directly up to the current-carrying ability of the tube. Reactance in the load, however, will disturb the firing point. Firing point of the thyratron is also a function of the source voltage, temperature and random effects such as r-f energy and will vary from tube to tube. It is important to design the thyratron amplifier so that the firing point is a stable function of the input signal.

Magnetic amplifiers also have a low inherent output impedance, but are sensitive to load impedance and supply voltage. In fact, magnetic amplifiers are usually designed for a specific application. Magnetic amplifiers, however, have long life and ruggedness comparable with that of transistor amplifiers. A more complete discussion of discontinuous amplifiers will be presented in a future section of this *Components Digest*.

TRANSISTOR AND VACUUM TUBE AMPLIFIERS

Transistor and vacuum tube amplifiers make up the bulk of audio amplifiers today because of their ability to amplify with a great degree of fidelity. The big question is, which is better, a vacuum tube amplifier or a transistor amplifier? A surprising amount of emotion has been generated by this question. Of course, there is no real answer, since each amplifier has its own characteristics and generally can be used most efficiently in different applications.

Transistor amplifiers can be made amazingly small, efficient, and rugged. For many military and computer applications, this characteristic is all important. Recently, however, tubes have recently been gaining in this respect with the advent of the cold cathode



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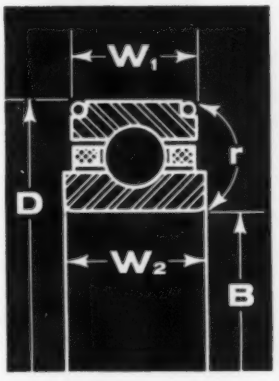

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TCR 17-24	1.0625	1.5000	.250	.281	24	1/8	.05	360	650
TCR 21-28	1.3125	1.7500	.250	.281	28	1/8	.06	370	760
TCR 25-32	1.5625	2.0000	.250	.281	34	1/8	.07	390	925
TCR 29-36	1.8125	2.2500	.250	.281	38	1/8	.08	410	1030
TCR 33-42	2.0625	2.6250	.250	.281	44	1/8	.12	435	1200
TCR 37-46	2.3125	2.8750	.250	.281	48	1/8	.13	450	1300
TCR 41-52	2.5625	3.2500	.312	.375	36	3/16	.22	835	2200
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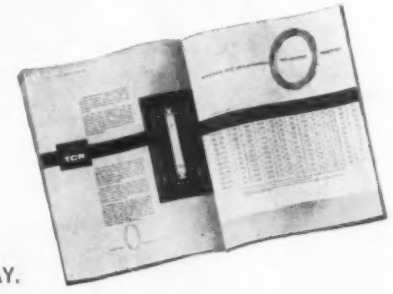

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TABLE I

The Basic Types of Audio Power Amplifiers

A. CONTINUOUS AMPLIFIERS

1. *Transistor Amplifiers:* small, efficient, rugged, long life, and no warm-up time, but transistors are non-uniform and especially temperature sensitive.
2. *Vacuum Tube Amplifiers:* temperature insentitive, quite uniform, and easily designed and used with existing system components, but they are larger, less rugged, and have shorter life than transistor amplifiers.

B. DISCONTINUOUS AMPLIFIERS

1. *Magnetic Amplifiers:* rugged, high output power, long life, no warm-up time, efficient, and no appreciable d-c power is required, but usually are expensive, have relatively slow response, and must be designed for a particular load and supply voltage.
2. *Thyratron Amplifiers:* high output power, efficient, and no appreciable d-c power required, but introduce dead time, are hard to control very accurately, and have shorter life and are less rugged than magentic amplifier.

and extreme miniaturization.

On the other hand, transistor amplifiers are inherently sensitive to temperature. As ambient temperature increases, the transistor amplifier must either saturate or burn out, depending upon the design. This problem is one of the most interesting aspects of transistor amplifiers and will be considered in some detail in the transistor amplifier section to follow. Tube amplifiers are quite insensitive to ambient temperature changes because their quiescent temperature is so high.

Design of transistor amplifiers is somewhat more difficult than design of vacuum tube amplifiers, not only because of the thermal problem, but because of other factors. One problem is the difficulty of converting from a-c to d-c at high current levels; larger capacitors are needed to decrease ripple. Also, interstage coupling is more difficult since transistor input impedance varies with output impedance, temperature, current, and voltage. The low in put impedance usually experienced makes transformer coupling desirable for its impedance matching. Transformers, however, are fairly large, especially in low-frequency amplifiers. Capacitor coupling also suffers from the low input impedance because the coupling capacitors must increase in size as input impedances decrease to achieve wide bandwidth. Direct coupling is actually simpler in transistor amplifiers than in vacuum tube amplifiers because of the lower voltage levels, but thermal drift problems are intensified by allowing the drift to be

coupled through the amplifier.

Probably the worst problem in designing transistor amplifiers is that the parameters vary not only with operating conditions but from unit to unit. Vacuum tubes are made in uniform lots because almost all of their important characteristics can be controlled mechanically. Transistors are made under controlled conditions, but their characterstics cannot be so accurately predicted. Consequently, from three or four different production lines, several hundred transistor types will be obtained, mostly by selection. Certain high-performance types will be rare and will also have a tendency to deteriorate with age into a more run-of-the-mill type of transistor.

Finally, we should point out a very interesting trend associated with the trade-off between vacuum tube and transistor amplfiers. This is based on the fact that transistors are basically current amplifiers with low input impedance and low output voltage. Tubes, on the contrary, are voltage amplifiers with high input impedance and large output voltage. In the past, electromechanical elements, such as motors, have been built for high input voltage as is available from vacuum tubes. Also, sensor and pck-up devices have been built with large impedance to work into the high impedance of a vacuum tube. The trend recently is to lower voltage motors and power elements whch are more easily driven by transistors. The trend will undoubtedly spread to pick-up devices and other components, possibly to such a degree that in the future voltage amplification might become a liability instead of the reverse, which is true today.

PART TWO

Transistor Audio Amplifiers

BASIC TRANSISTOR

The purpose of this article is to aid the engineer in evaluating packaged transistor amplifiers. To do this, however, some of the basic design fundamentals must be presented.

This discussion, of course, must start with the transistor itself. A transistor can be roughly described as being two back-to-back diodes as in Figure 1. A pnp transistor is shown and will be used in the following discussion, but an npn is exactly the same with just the diodes reversed. In linear amplifier operation, the base element is kept at a lower d-c potential than that of the emitter which means that the emitter to base diode is forward biased. Also, the collector is at a lower potential than that of the base which means that the base to collector diode is back biased.

Looking into the transistor between the base and emitter we would see the forward resistance characteristic of a diode as sketched in Figure 2. For appreciable values of emitter current, this curve looks a lot like a battery with a voltage V_{EO}. The voltage V_{EO} is between 0.1 and 0.7 volts, depending upon the temperature at the diode and the type of semiconductor material used (silicon being higher than germanium). In most practical circuits, the external resistances in series with the leads on the transistor are of such a magnitude that these internal resistances and voltage drops can be neglected. The transistor can also be considered as very nearly an ideal current source for most stable amplifier designs. With these two simplifications, an elementary model for a transistor can be drawn as in Figure 3.

The equivalent circuit in Figure 3 shows that the collector looks like an ideal current source whose magnitude is "α" times the emitter current. This is the key to the transistor's amplification because in most transistors α is between 0.95 and 0.99. Consequently, $(\alpha/1-\alpha)$is quite large which means that the collector current (i_C) will follow small variations in the base current (i_B).

$$i_C \cong (\alpha/1-\alpha)i_B = \beta\, i_B$$

Figure 3 shows the simplest possible mathematical model of the transis-

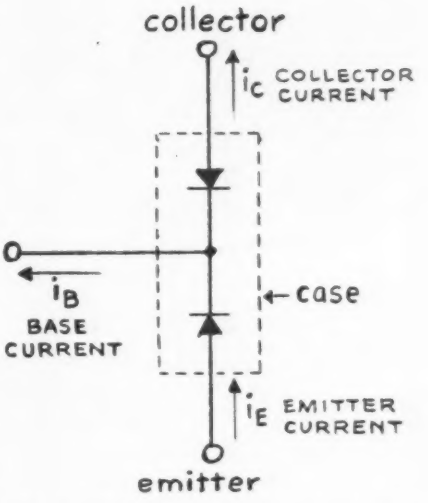

Fig. 1 First approximation to a PNP transistor.

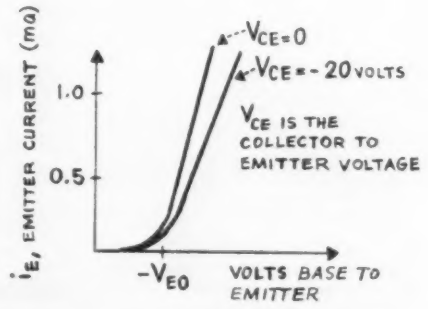

Fig. 2 Input characteristic of a transistor.

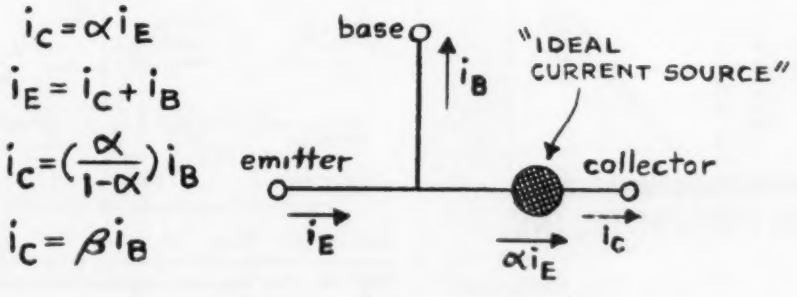

Fig. 3 Simplest transistor model.

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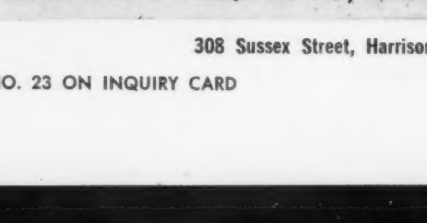

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COMPONENTS DIGEST

tor. If we want a more exact model, the choice becomes more difficult because, as with most mathematical problems, the equations can be set-up in many ways. The important point, however, is that each set of equations or model describes exactly the same problem. The most popular models are the "r" parameter or "T" equivalent circuit (Fig 4a) and the "h" parameter 4 terminal equivalent circuit (Fig 4b).

In general, the "T" equivalent lends itself to simple analysis while the "h" parameters are easiest to measure. Consequently the manufacturer gives the transistor characteristics in terms of "h" parameters. The different "h" parameters and their conversion to "r" parameters are presented in Table II.

It should be noted that although these models will describe the effect of d-c signals on the transistor, they are usually used as an a-c equivalent.

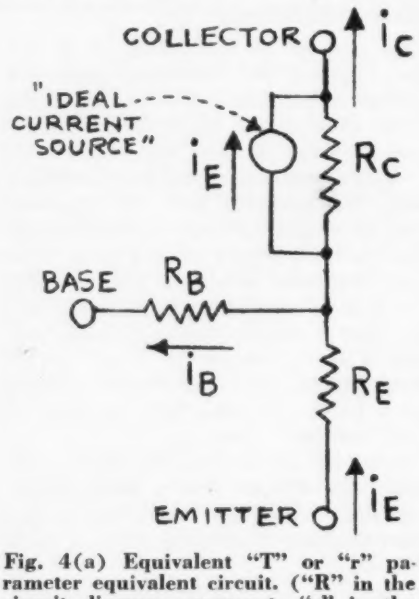

Fig. 4(a) Equivalent "T" or "r" parameter equivalent circuit. ("R" in the circuit diagram represents "r" in the text.)

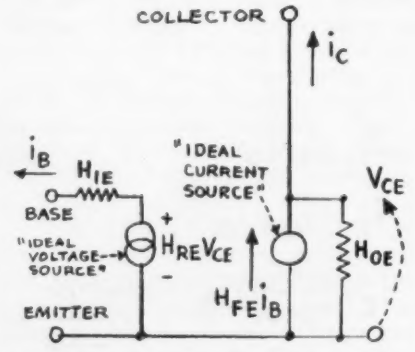

Fig. 4(b) Four terminal "h" parameter equivalent circuit. ("R" and "H" in the circuit diagram represent "r" and "h" in the text.)

TABLE II
Conversion from "h" to "r" Parameters

APPROXIMATE "r" PARAMETERS	COMMON BASE "h" PARAMETERS	COMMON EMITTER "h" PARAMETERS	COMMON COLLECTOR "h" PARAMETERS
r_e	$h_{ip} - \frac{h_{rb}(1+h_{fb})}{h_{ob}}$	$\frac{h_{fe}}{h_{oe}}$	$\frac{1-h_{rc}}{h_{oc}}$
r_c	$\frac{1}{h_{ob}}$	$\frac{(1+h_{fe})}{h_{oe}}$	$-\frac{h_{fc}}{h_{oc}}$
r_b	$\frac{h_{rb}}{h_{ob}}$	$h_{ie} - \frac{h_{re}(1+h_{fe})}{h_{oe}}$	$h_{ic} - \frac{h_{fc}(1-h_{rc})}{h_{oc}}$
α	$-h_{fb}$	$\frac{h_{fe}}{1+h_{fe}}$	$\frac{h_{fc}+1}{h_{fc}}$

The "r" parameter or "T" equivalent circuit is easiest to analyze, but the "h" parameters are easiest to measure. Small case letters are used for A.C. or small signal values and upper case letters for D.C. values. The second letter in the "h" parameter refers to the common element in the transistor. For example, h_{fe} is the A.C. forward current gain of a common emitter transistor, while h_{FE} is the D.C. gain of the same configuration. (Note that the D.C. current gain is used for the bias calculations in the body of the article, although there is generally little difference between h_{fe} and h_{FE}).

The four terminal equivalent or "h" parameters can be defined by the two equations written below for a common emitter case.

$e_{be} = h_{ie}\, i_b + h_{re}\, e_{ce}$
$e_{ic} = h_{fe}\, i_b + h_{oe}\, e_{ce}$

The following terms can be applied under the conditions defined by the equations:

h_{ie} input impedance
h_{oe} ouput admittance
h_{fe} forward current gain
h_{re} reverse voltage ratio

An a-c equivalent describes the effect of small signal swing about some d-c operating point. The parameters of the models will, therefore, only be exact in a small region about some d-c level. Variation in the "h" parameters with these d-c levels is sketched in Table 3. Table 3 also shows the variation with temperature.

Table 4, included as a reference, lists the quantitative and qualitative characteristics of the three basic transistor connections for the "T" equivalent circuit.

BIASING

We have mentioned that the base must be biased negatively with respect to the emitter and that the collector must be negative with respect to the base. The problem, however, is what are the best d-c bias levels? To investigate this question assume the grounded emitter transistor circuit shown in Figure 5. The static collector characteristics are shown in Figure 6 with the load line $(1/R_L)$. The load line is drawn from the maximum collector voltage, E_C, to the maximum collector current, E_C/R_L.

The best bias for linear amplification is that value of base current that allows maximum undistorted signal swing at the collector. This bias, from the sketch in Figure 6, seems to be a base current of i_{B4} such that the quiescent collector current is i_C' and the quiescent collector voltage is V_C'.

The bias can be achieved in a number of ways. The simplest is shown in Figure 7. This scheme is slightly precarious because the value of collector current depends upon the transistor's current gain, β. The introduction pointed out that current gain varies widely from transistor to transistor and can also vary with storage time and environmental conditions. As a point of interest, a vacuum tube can be self-biased because the control grid can be biased negative by the cathode cur-

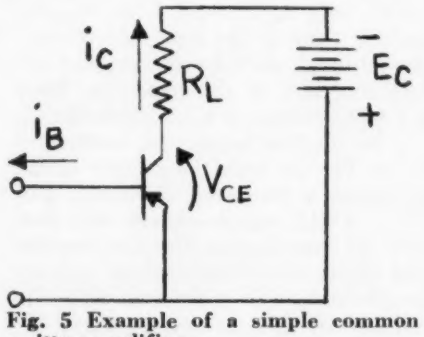

Fig. 5 Example of a simple common emitter amplifier.

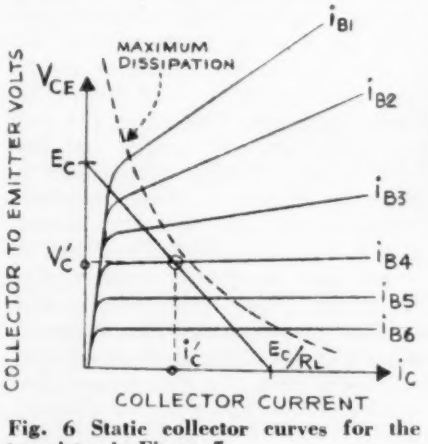

Fig. 6 Static collector curves for the transistor in Figure 5.

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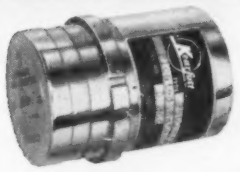

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TYPICAL CHARACTERISTICS

Mass Unbalance:
Along Input Axis: 1.0°/ hr maximum untrimmed
Standard Deviation (short term):
Azimuth Position: 0.05°/hr
Vertical Position: 0.03°/hr
Drift Rate Due to Anisoelasticity
Steady Acceleration:
.015°/hr./g² maximum
Vibratory Acceleration:
.008°/hr./g² maximum
Damping:
Ratio of input angle to output angle is 0.2
Characteristic Time:
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Weight: 0.7 lbs.
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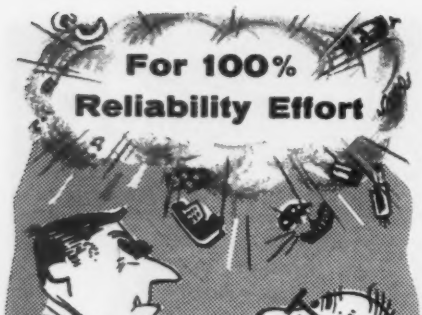

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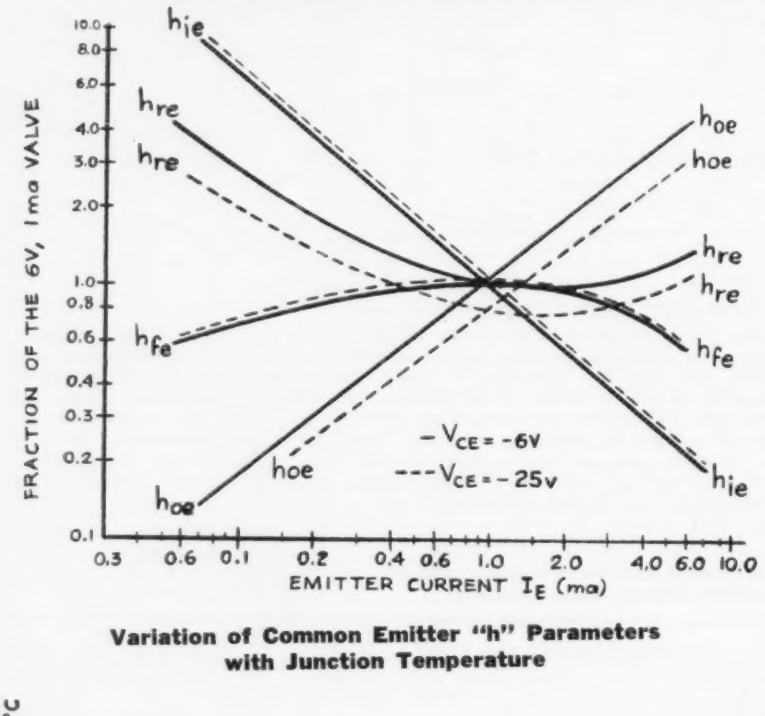
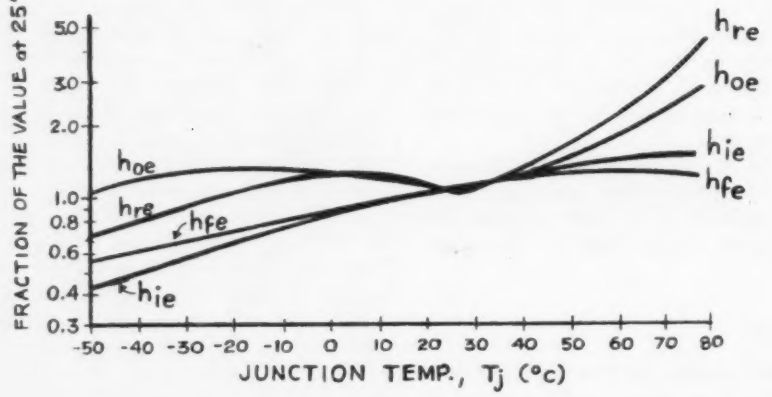
TABLE III
Variation of Common Emitter "h" Parameters with Emitter Current and Collector Voltage



Variation of Common Emitter "h" Parameters with Junction Temperature



rent, while in a transistor the base must be biased negative in opposition to the emitter current.

The general objective of a biasing scheme is not only to achieve maximum signal swing at the output but to also insulate the quiescent conditions from parameter variations. The scheme in Figure 7 failed on the second count. A better design and the most common biasing arrangement is shown in Figure 8. Two important changes were made: a second biasing resistor, R_{B2}, was added from base to ground and an emitter resistor, R_E, was added. The second scheme was designed to eliminate the quiescent collector current's sensitivity to changes in current gain. To demonstrate the improvement, compare the incremental ratio $\Delta i'_C/\Delta\beta$ for the two biasing arrangements.

Figure 7:

$$(\Delta i'_C/\Delta\beta) \cong E_C/R_B$$

Figure 8:

$$(\Delta i'_C/\Delta\beta) \cong (E_C/R_{B1})/[\beta R_E/R_{B1} /\!/ R_{B2} + 1]^2$$

$(\Delta i'_C/\Delta\beta)$ approaches zero as either βR_E or R_{B1} increases or R_{B2} decreases in Figure 8.

As R_{B1} and R_E increase, while R_{B2} decreases, more of the input current will flow through the bias resistors and not into the base of the transistor. Since the input current is a-c, a capacitor C_E can be used to bypass the emitter resistor. The a-c input impedance of the transistor is therefore decreased and more of the signal current will flow into the base. In this way the insertion loss of the second bias resistor and the emitter resistor is minimized while the stability of the d-c quiescent conditions is retained.

COMPONENTS DIGEST

LEAKAGE CURRENT

The worst problem in biasing is yet to be faced. This is the leakage current, I_{CBO}, flowing through the back biased base to collector diode. The leakage current is due to two causes: First, I_O, the current flowing through the semi-conductor material; and, second, I_L, the current flowing across the surface connections. I_O is a function of the semi-conductor material and doubles for about every 10 degree centigrade increase in temperature. I_L is a function of the structure of the base to collector junction and varies with the manufacturing process. I_L also increases nonlinearly with increasing base to collector voltage, V_{CB}. When V_{CB} increases, I_{CBO} increases with the I_L component, but the actual diode breakdown or avalanche is due to a sharp increase in I_O, the bulk property leakage current.

The leakage current is always drawn through the base to collector diode and will appear in the collector current, i_C, so that:

$$i_C = \alpha i_E + I_{CBO}$$

More important, however, is that since I_{CBO} is drawn through the base it could be amplified in the collector circuit by the current gain. A third objective of the biasing network must therefore be to hold the effect of I_{CBO} to a minimum.

THERMAL STABILITY

To show how badly the collector current increases for an increase in leakage current, we will use the incremental ratio $\Delta i_C/\Delta I_{CBO} = S$. S is called the stability factor or more exactly the instability factor because it decreases with thermal stability. The solution for

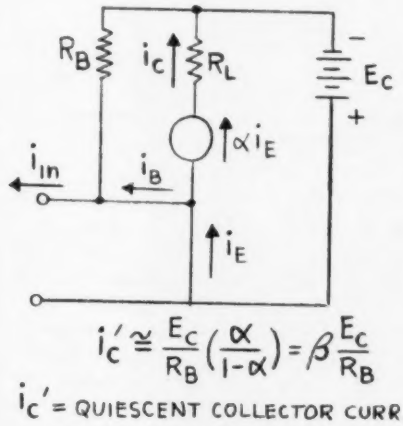


Fig. 7 Simplest biasing scheme.

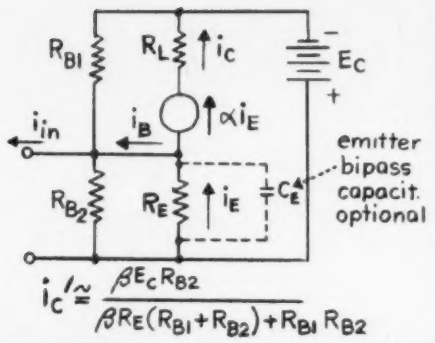


Fig. 8 Most common biasing scheme for common emitter amplifier.

the S in Figure 8 is quite simple once we recognize that i_B flows to ground through two paths. One is directly through R_{B2} and the other is through R_{B1} and the battery E_C. The base to emitter voltage change, ΔV_{BE}, must then be the base current change, Δi_B, times the parallel resistance of R_{B2} and R_{B1} (denoted $R_{B1} /\!/ R_{B2}$).

$$\Delta V_{BE} = \Delta i_B (R_{B1} /\!/ R_{B2})$$
$$= (\Delta i_C - \Delta i_E)(R_{B1} /\!/ R_{B2})$$
$$\Delta V_{BE} = R_E \Delta i_E$$
$$\Delta i_C = \alpha \Delta i_E + \Delta I_{CBO}$$
$$(\Delta i_C/\Delta I_{CBO}) = [R_E + (R_{B1} /\!/ R_{B2})]/[R_E + (R_{B1} /\!/ R_{B2})(1-\alpha)] = S$$

Now when $R_E = 0$ and I_{CBO} is drawn through the base, the collector current is increased by $(1/1-\alpha)$ $I_{CBO} \cong \beta I_{CBO}$. This is the maximum effect of the leakage in the collector current. With a large R_E and smaller bias resistors (similar to a grounded base), the collector current is only increased by the absolute value of the leakage, I_{CBO}. This second case is a minimum where I_{CBO} caused no amplified effect upon the collector current.

As increasing I_{CBO} increases the collector current, the bias point in Figure 6 will move down the load line towards saturation. This motion will occur more or less rapidly depending upon the value of the thermal stability factor, S. If the load line is positioned as in Figure 6, the transistor will saturate before it exceeds maximum dissipation. Had the load resistance been smaller or the collector voltage larger, the transistor might have failed from over dissipation before the quiescent point reached saturation. Maximum dissipation in Figure 6 was drawn for an assumed heat sink. The relationship between maximum dissipation and thermal conductivity will be discussed later.

THERMAL RUN-AWAY

Under certain conditions, a small increase in I_{CBO} will increase itself, driving the quiescent point completely to saturation or into excessive dissipation. This condition is called "thermal run-away" and is a function of the thermal stability factor, S.

Run-away occurs whenever a small

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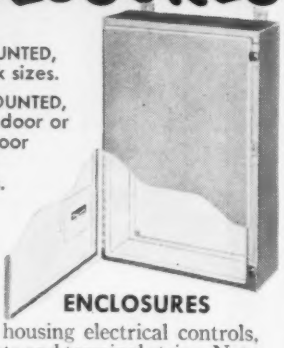

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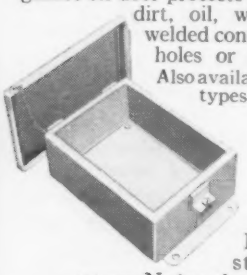

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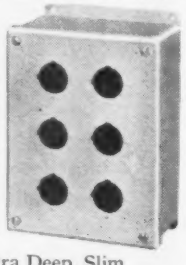

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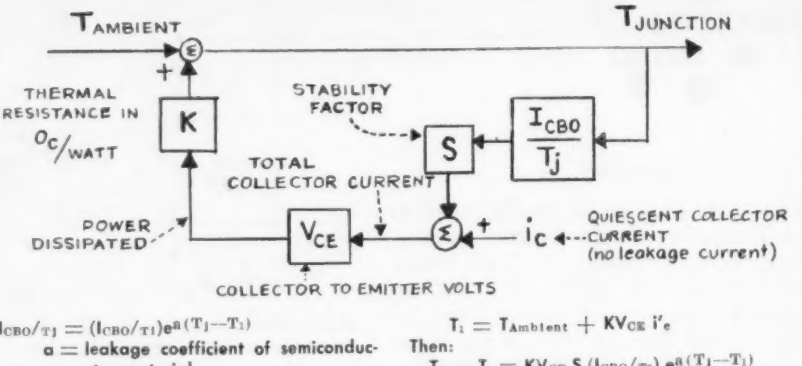


$I_{CBO/Tj} = (I_{CBO/T1})e^{a(T_j - T_1)}$

a = leakage coefficient of semiconductor material

$I_{CBO/Tj}$ = leakage current at junction temperature, T_j.

T_1 = an arbitrary reference junction temperature.

The final junction temperature must therefor be:

$$T_j = T_{Ambient} + KV_{CE}\, i'_e + KV_{CE}\, S \times I_{CBO/Tj}$$

If we assume for convenience that T_1 is the junction temperature with absolutely no leakage current:

$$T_1 = T_{Ambient} + KV_{CE}\, i'_e$$

Then:

$$T_j - T_1 = KV_{CE}\, S\, (I_{CBO/T1})\, e^{a(T_j - T_1)}$$

$T_j - T_1$ is therefore the increase in junction temperature due to leakage current.

M. J. Hellstrom solved this equation on Page 24-25 of *Semi-Conductor Products*, Jan. 1959. He found that for the junction temperature to be absolutely stable the following condition must be met:

$$KV_{CE}\, S\, (I_{CBO}/T_1) \leqslant 1/2.72\, a$$

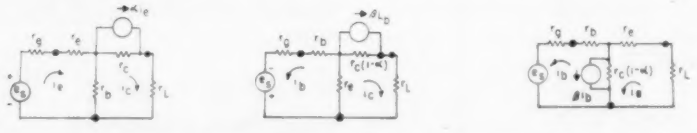
$1/2.72\, a$ for germanium varies between 6.12 and 4.09. The leakage coefficient for silicon is about ½ that of germanium.

Fig. 9.

TABLE IV

Characteristics of the Three Basic Transistor Connections for the "T" Equivalent Circuit

Approximate Values for Common Base	*Approximate Values for Common Emitter*	*Approximate Values for Common Emitter*
Input Resistance (qualitative)		
$r_e + r_b\,(1 - a)$	$r_b + r_e/1 - a \sim r_b + \beta r_e$	$r_L/1 - a = r_L\,(\beta + 1) \sim \beta r_L$
Output Resistance (qualitative)		
$(r_c)\,(r_e + r_g + r_b)\,(1 - a)$ / $(r_e + r_g + r_b)$ *(largest)*	$(r_c)\,(1 - a) +$ $(r_e)\,(r_m + r_g)/(r_e + r_b + r_g)$ *(medium)*	$r_e + (r_b + r_g)\,(1 - a)$ *(smallest)*
Voltage Amplif. A_v (qualitative)		
$(a\, r_L)/(r_e + r_b)\,(1 - a)$ *(large)*	$(-a\, r_L)/(r_e + r_b)\,(1 - a)$ *(large)*	1 *(unity)*
Current Amplif. A_i (qualitative)		
a *(unity)*	$a/1 - a = \beta$ *(large)*	$1/1 - a = \beta + 1 \sim \beta$ *(large)*
Power Gain P_g (qualitative)		
$(a^2 r_L)/(r_e + r_b)\,(1 - a)$ *(medium)*	$(a^2 r_L)/(1 - a)^2 (r_e + r_b)$ *(highest)*	$1/1 - a = \beta + 1 \sim \beta$ *(lowest)*



In a normal circuit external resistances are present. These external resistances can be added to the internal resistances in the equivalent circuits without distorting the characteristic solutions. For example if an external resistance, R_E, is added to the emitter in a common emitter stage, the input impedance will equal:

$$r_b + (r_e + R_E)/(1 - a) \sim r_b + \beta\,(r_e + R_E)$$

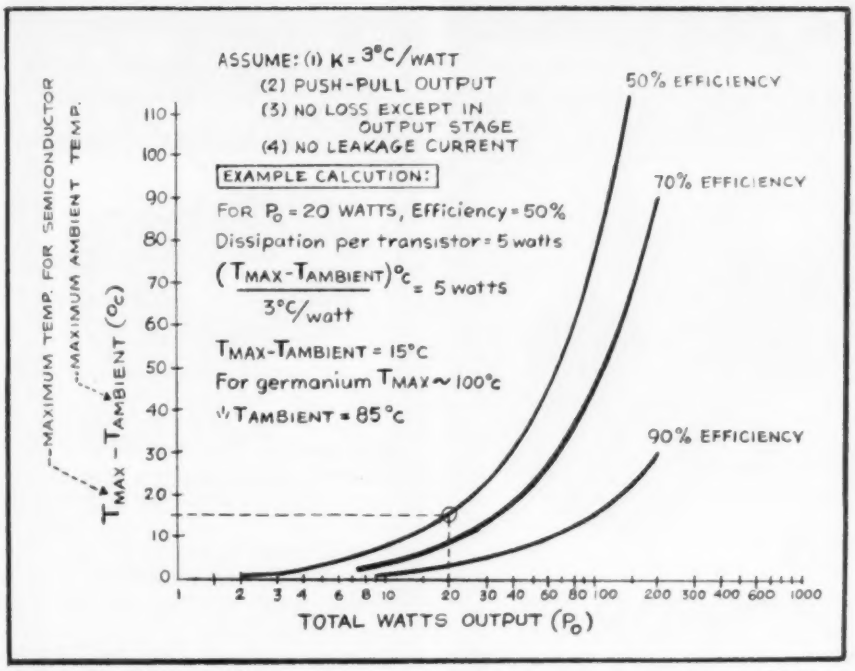

ASSUME: (1) K = 3°C/WATT
(2) PUSH-PULL OUTPUT
(3) NO LOSS EXCEPT IN OUTPUT STAGE
(4) NO LEAKAGE CURRENT
EXAMPLE CALCUTION:
FOR P_o = 20 WATTS, Efficiency = 50%
Dissipation per transistor = 5 watts
$\frac{(T_{MAX}-T_{AMBIENT})°C}{3°C/watt}$ = 5 watts
$T_{MAX}-T_{AMBIENT}$ = 15°C
For germanium T_{MAX} ~ 100°C
∴ $T_{AMBIENT}$ = 85°C
50% EFFICIENCY
70% EFFICIENCY
90% EFFICIENCY
MAXIMUM TEMP. FOR SEMICONDUCTOR
MAXIMUM AMBIENT TEMP.
$T_{MAX} - T_{AMBIENT}$ (°C)
TOTAL WATTS OUTPUT (P_o)

Fig. 10 Maximum ambient temp. as a function of power output and efficiency.

TABLE V

Check List of Important Transistor Power Amplifier Characteristics

1. **Frequency Response**
   a. Low frequency phase shifts can be caused by small coupling capacitors, small bi-pass capacitors, or small transformers.
   b. High frequency phase shifts can be caused by low "a cut-off" power transistors or by a capacitor used to tune the output for an inductive load.
   c. Feedback can increase bandwidth but it can also introduce peaking at the resonant frequency of the closed loop.
2. **Power Output and Output Impedance**
   Most transistor amplifiers are expected to supply a maximum of about 40 volts. This means that 115 volt motors are not used even if their impedance matches the amplifier.
   a. check maximum (unsaturated) power supplied by the amplifier.
   b. check load impedance into which amplifier supplies this maximum power.
   c. Combine amplifier with electromechanical element which fits these characteristics.
3. **Input Impedance**
   In most cases the input source has a high internal impedance. The amplifier's input impedance must match the source impedance fairly well especially if the source delivers low power. In transistor amplifiers the input impedance is normally low, 2,000 to 50,000 ohms depending upon the emitter resistor. Many circuits, however, have been devised to produce larger input impedance, generally with a loss of gain.
4. **Gain Stability and Linearity**
   a. The small signal gain decreases as the output increases until saturation is reached. The linear range for which small signal gain is essentially constant must be checked.
   b. In the linear region the gain can still vary with temperature and line voltage.
5. **Power Supply**
   a. Voltage spikes from the power supply can permanently damage a transistor.
6. **Harmonic Distortion and Noise**
   a. Harmonic distortion can vary with temperature as the operating point moves with the leakage current.
   b. Noise should be checked if very low frequency operation is important.
7. **Sensitivity to Environment** such as shock, dust, etc.
8. **Life Expectancy**
9. **Versatility**
10. **Expense**

increase in leakage causes the junction temperature to rise enough to cause even a larger increase in leakage current. The leakage current increases the junction temperature by increasing the collector current and, consequently, the collector junction dissipation which, in turn, increases the junction temperature.

This process is more easily described by the block diagram in Figure 9. The leakage current, I_{CBO}/T_j, is shown to be an exponential function of the junction temperature, T_j. The stability factor, S, times the leakage current equals the increase in collector current. We have been assuming that the transistor is an ideal current source which means

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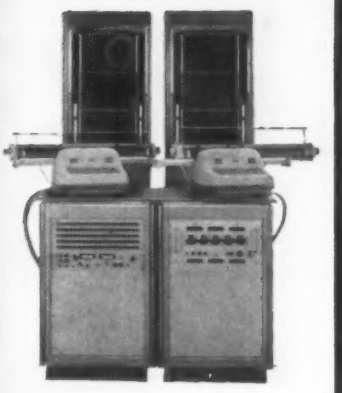

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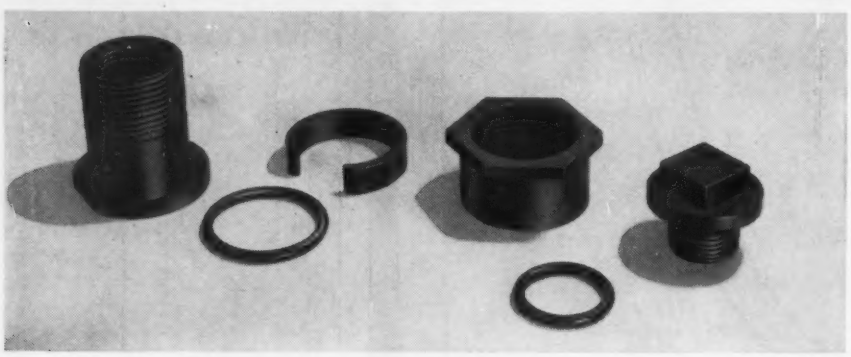

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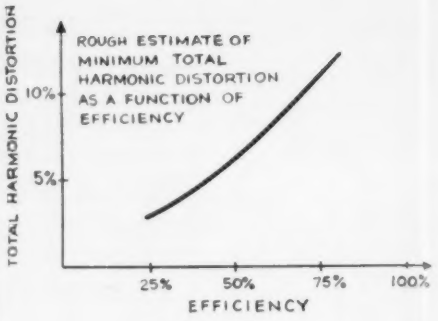

Fig. 11

that the base-to-collector voltage, which equals the collector-to-emitter voltage in our model, is independent of collector current. Power dissipated at the collector junction is then just the collector current times the constant collector-to-emitter voltage, V_{CE}. Junction temperature is equal to ambient temperature plus power dissipated times thermal resistance between the junction and air.

Figure 9 shows that the absolute thermal stability can be assured by satisfying the following condition:

$$S\,V_{CE}\,K\,I_{CBO}/T_1 = 1/2.72\,a$$

K = thermal resistance (discussed later).

I_{CBO}/T_1 = leakage current at a junction temperature T_1.

T_1 = junction temperature with no leakage = Tambient + $K\,S\,V_{CE}\,i_C'$.

a = leakage coefficient of the semiconductor material which for germanium varies between 16.7 and 11.1. The coefficient for silicon is about half that of germanium.

The above equation only defines the absolute thermal stability. As the transistor approaches the limit, holding the bias constant will become increasingly difficult.

NONLINEAR BIASING

The problem of stable biasing, either against variations in parameter or temperature, is extremely important from the view of evaluating packaged transistor audio amplifiers. So far, we have discussed only the most fundamental circuits, and, of course, a great many variations have been devised. Two nonlinear biasing techniques should be mentioned as an example of the type used to compensate the leakage current.

The first is based on using a thermistor in the circuit. A thermistor is a device whose resistance decreases with temperature. It can be used in a number of ways, but bascially its effect is to decrease the emitter current with temperature, to compensate for the increase in emitter current due to increased leakage current. The second method is to use a back-biased diode

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TYPICAL CHARACTERISTICS

Kearfott Unit No.	P1241-11A
Code	Cyclic Binary
Range	0-32,768 (2^{15})
Bits per Revolution	16
Revolutions for Total Range	2,048
Volts D.C.	10.5
Current (ma.)	20
Inertia (gm. cm.^{2})	20
Unit Diameter (in.)	1 1/16
Unit Length (in.)	3
Life 10^6 Revolutions or 10^3 hours	
Static Torque (in.-oz.)	2 (break) 1 (running)
Weight (oz.)	5
Maximum Speed (RPM)	600

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TYPICAL CHARACTERISTICS — SIZE 25

	Transmitter	Control Transformer
Type Resolver		
Part Number	Z5161-001	Z5151-003
Excit. Volts (Max.)	115	90
Frequency (cps)	400	400
Primary Imped.	400/80°	8500/80°
Secondary Imped.	260/80°	14000/80°
Transform. Ratio	.7826	1.278
Max. Error fr. E.Z.	20 seconds	20 seconds
Primary	Rotor	Stator

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Kearfott integrating tachometers, special types of rate generators, are almost invariably provided integrally coupled to a motor. They feature tachometer generators of high output-to-null ratio and are temperature stabilized or compensated for highest accuracy integration and rate computation. Linearity of these compact, lightweight tachometers ranges as low as .01% and is usually better than ± .1%.

TYPICAL CHARACTERISTICS

	Size 11 (R860)
Excitation Voltage (400 cps)	115
Volts at 0 rpm (RMS)	.020
Volts at 1000 rpm (RMS)	2.75
Phase shift at 3600 rpm	0°
Linearity at 0-3600 rpm	.07
Operating Temperature Range	−54° +125°

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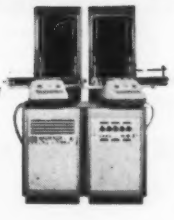
Miniature Floated Gyro

Electrohydraulic Servo Valve

Scanalog 200-Scan Alarm Logging System



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CIRCLE NO. 19 ON INQUIRY CARD

ON SYNCHROS
CIRCLE NO. 20 ON INQUIRY CARD

ON TACHOMETERS
CIRCLE NO. 22 ON INQUIRY CARD

COMPONENTS DIGEST

in place of R_{B1} in Figure 8. If this bias diode has the same characteristics and temperature as the back-biased base-to-collector diode the leakage currents will be equal and the emitter current will remain unchanged.

THERMAL RESISTANCE

Heat is dissipated from the junction through the transistor case to the mounting and finally to the air. The heat conduction is usually measured by its inverse, or thermal resistance, K. Thermal resistance is the number of degrees of temperature change between the point under consideration and the heat source per watt of power dissipated at the heat source.

For example, a typical thermal resistance from a power transistor junction to its case is 1.5 degrees C/watt. The thermal resistance from the case to air depends upon the transistor mounting to the chassis, the size of the chassis, the flow of air, and many other factors. A good thermal resistance from the junction of an audio power transistor to air is 3 degrees C/watt (no fan). If the unit achieves this figure, it is quite well designed thermally.

The thermal resistance, K, played a very important part in the thermal stability calculations. It is especially important because the heating of the junction of a transistor has an upper temperature limit. The junction can be destroyed if, for germanium, it exceeds about 100 degrees C, or, for silicon, about 200 degrees C.

OPERATING TEMPERATURE RANGE

If I_{CBO} were always zero, a curve of the maximum ambient temperature could be drawn, as in Figure 10, as a function of the power output and the efficiency. In Figure 10, we have assumed there is no leakage, the output is push-pull (almost universal), there is no loss in power except in the last stage, and thermal resistance, K, is 3 degrees C/watt. This curve can be used as an evaluation aid since it shows the largest possible temperature range for any set of conditions. The temperature range is given as a function of T_{max} (the junction limit), so that either semiconductor material could be considered.

EFFICIENCY AND DISTORTION

Efficiency plays an important role in evaluating the temperature range. Efficiency, however, is usually a trade-off against harmonic distortion. Harmonic distortion is a measure of how well the output wave shape follows the input. For example, if the input is a sinewave and the output a square wave, quite a few harmonics must have been generated in the amplifier. To measure the total harmonic distortion, we would find the percentage of each harmonic with respect to the fundamental and we would combine all the percentages on an r.m.s. basis.

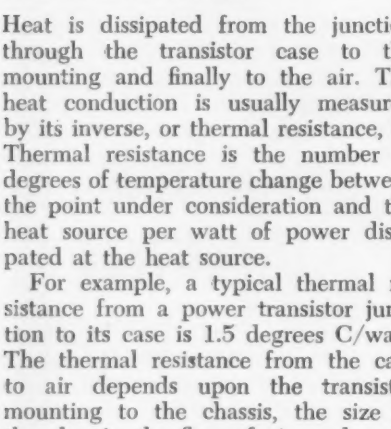
Distortion in a transistor amplifier is usually traced to the output stage. This distortion can be caused by a number of factors:

- Variation of current gain with emitter current. Table 3 shows a dropping off in h_{fe} with emitter current. This would have the effect of rounding off large signal peaks.
- Variation of input impedance with emitter current. If the source has a finite resistance, variations in transistor impedance will change the input current. Actually, sometimes variation due to impedance can compensate variation due to current gain.
- In a push-pull output stage, even harmonics are reduced. If the two transistors, however, do not have an equal current gain, a lopsided output wave will result. Also, if the two transistors vary differently with output current or temperature, extra distortion will result.
- In a class B push-pull stage, cross-over distortion can result. Cross-over distortion is caused by drop-off in current gain and increase in input impedance for small signals. One cure for this distortion is a little forward bias. This forward bias, however, lowers efficiency. Quite a few circuits have been developed to produce a small forward bias for small signals and a lower, class B, bias for larger signals.

Table 3 shows that both the input impedance and the current gain will change with temperature.

FEEDBACK

One way to decrease distortion is to use negative feedback, either around a number of stages or locally. Negative feedback, however, has the effect of decreasing gain and efficiency. A rough curve of total harmonic distortion versus efficiency is given in Figure 11. This curve was not rigorously determined and is only meant as a general guide.



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FREQUENCY RESPONSE

An important characteristic of the transistor amplifier is its frequency response. Frequency response within the amplifier is also a factor in using negative feedback to reduce distortion. If large phase shift occurs within the feedback loop, relative instability results. Many factors affect phase shift; one is the basic transistor itself. Transistors have a definite frequency dependent character which is usually measured by its "α cut-off" frequency, f_{ab}. The f_{ab} is the frequency at which the common base current gain, α, decays by 3db. The f_{ab} for power transistors can be as low as 4,000 cycles/sec.

Other contributions to phase shift come from the external circuit. Coupling capacitors were mentioned in the Introduction because a phase lead results from the time constant of the coupling capacitor and the input impedance of the following stage. Also, the time constant of the emitter resistor and the bi-pass capacitor causes leading phase shift.

Transformers contribute a leading phase shift whose time constant is the magnetizing inductance at the primary over the transformer's load reflected into the primary. To decrease this inductance, larger transformer cores are required. Another contribution can be obtained from tuning capacitors. Many times maximum power is delivered into a resistive load which means that increased output power can be realized by tuning an inductive load (such as a motor) with a capacitor. A resonance results and, if the Q is not too great, the resulting phase shift can be tolerated in narrow band amplifiers such as those used in a-c servos.

NOISE

Noise in a transistor amplifier can be attributed to either noise at the input, noise generated internally in the transisor, or external noise such as pick-up, power supply ripple, and noise from the resistors in the circuit. The last type of noise is not unique to a transistor except that ripple in a current supply is harder to eliminate than ripple in a voltage supply. The best measure of noise is the noise figure, F, which equals the noise power at the output divided by the noise power at the input times the amplifier gain. In a transistor amplifier, F is generally quite flat from about 500-1000 cycles/sec. out to the "α cut-off" frequency. For frequencies lower than 500-1000 cycles/sec., F increases at about 3db/octave. Noise in the flat region is due mostly to thermal and shot effects. Increased noise at low frequency is blamed on the recombination of electrons and holes in the semiconductor.

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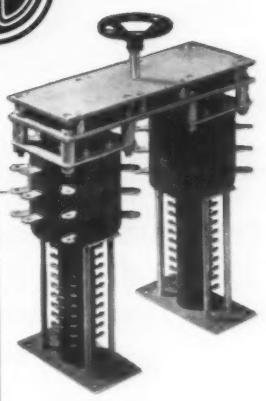
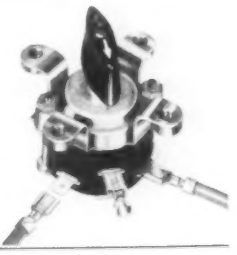
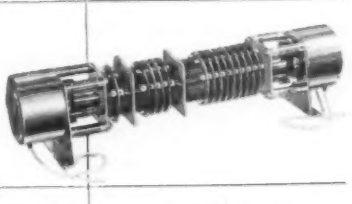
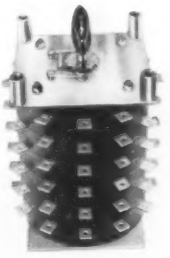
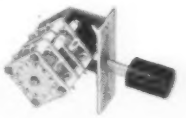
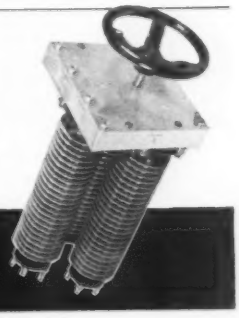
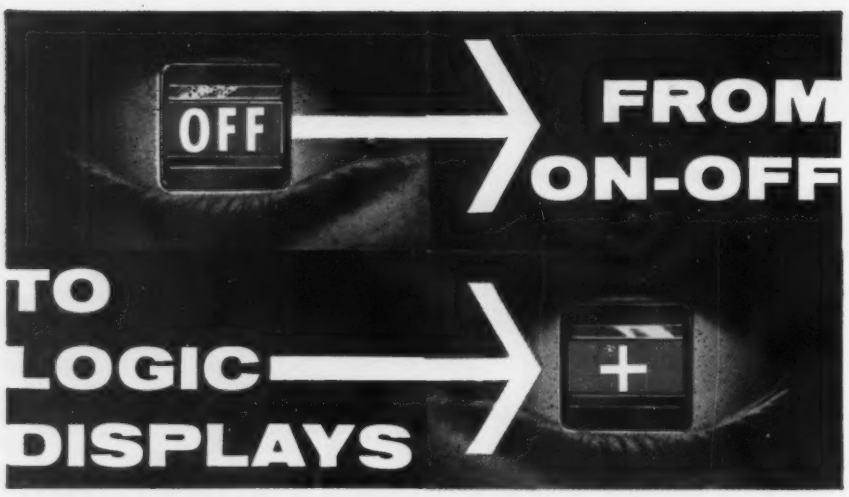


Style and Size	Loads and Circuits	
Single-control tandem pair; snap-action; 7 × 19 inches × 20 inches behind panel. 75 lbs. approx.	200 amps. 500 v. a-c 6-pole, triple-throw; 30 amps. 500 v. a-c 20-pole, triple-throw.	
Quick-connect terminaling for snap-on wiring; 3¼ inches diameter, 3 inches behind panel. 8 oz. approx.	10 amps. 125 v. a-c single-pole 4-position; snap action.	
2-way drive by 6-volt solenoids; 3⅞ inches diameter, 18½ inches long. 12 lbs. approx.	10 amps. 125 v. a-c 34 poles, 2 positions.	
High-current low-voltage tap switch; 10¾ × 10¾ inches, 14 inches behind panel. 25 lbs. approx.	150 amps. 6 v. a-c 6-pole 12-position.	
Lever-actuated miniature switch; 1¼ × 1¾ inches. 1¼ inches behind panel. 2 oz. approx.	3 amps. 125 v. a-c 4-pole 3-position.	
3-gang, gear-drive single-control switch; 6⅝ × 7⅛ inches × 14 inches behind panel. 25 lbs. approx.	5 amps. 125 v. d-c 75 poles 2 positions.	

ESCO of WEYMOUTH
ELECTRO SWITCH CORPORATION
167 King Avenue, Weymouth 88, Massachusetts

CIRCLE NO. 26 ON INQUIRY CARD



ALLARD ELECTROMAGNETIC INDICATORS GIVE YOU POSITIVE SIGNALING IN MITE-SIZE PACKAGES

Designed expressly for compact instruments and control panels, Allard miniature indicators meet the most critical requirements for small size, low power drain, positive performance in extreme environments.

Unlike lamp signals they are not subject to burnout, provide high readability even in strong incident light. What's more—Allard indicators offer unparalleled application flexibility, permit complex indications without the need for relays or grouping of multiple units.

Typical of the wide range of Allard signals available for demanding airborne or ground service are those shown here. All can be supplied to meet most specifications for display, operating voltage and mounting, in models for either military or industrial applications.

TYPE 101:

TYPE 103:

TYPE 109: 2 position. Suitable for compact rectangular cases, permitting extreme mounting flexibility. Face can be lettered or colored to specifications; overlaying faces available to order. DC to 50 volts. Dimensions: 0.270" by 9/16" by 15/16".

TYPE 110: For signals requiring full word or similar display. 2 position momentary or magnetic latching. 3 position momentary. All voltages to 50 v. d.c., input power 0.3 watt. Face 1" by 3/4" high, overall length 1⅝".

If your design demands visible signals, you'll want to have full technical and application information on the complete line of Allard indicators.

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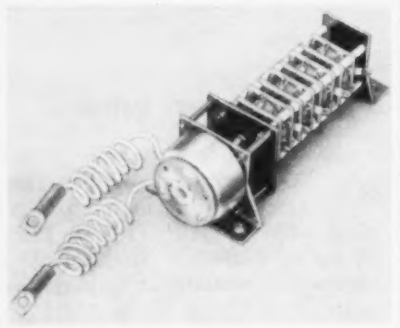


Solenoid-Operated Rotary Switch

New solenoid-operated switches provide for remote control of multiple circuits with a compact rotary switch mechanism. Up to five poles, in a tap switch arrangement having twelve taps per pole, can be supplied. Solenoid coils are available for d-c voltages ranging from 6 volts to 230 volts. Self-interrupting contacts as well as suitable rectifiers for a-c operation are also available. The solenoid requirements in terms of available power supply, pulsing method (mechanical and/or electrical), frequency of operation, number of operations, and ratio of energized time to de-energized time are arranged to customer specifications. All current carrying parts are silver-alloy material assuring low contact resistance for the life of the switch. Insulation is molded alkyd type MAI-60, per MIL-M-14E. The basic switch is designed to meet MIL-S-3786. Electro Switch Corporation, Weymouth, Mass.

Circle No. 157 on Inquiry Card.

Miniature Torque Pickup

New miniature torque pick-ups are available for a variety of low torque measurements in laboratory testing and product measurements. Typical sensitivities of standard models are 50, 100, and 250 inch ounces full scale, with useful speed ranges up to 10,000 rpm. Applications include: testing and design of small motors, gyros, selsyns, synchros, and actuators; evaluation of gear trains and servo systems; low torque dynamometer tests and similar measurements. Electrical sensitivity of the pickups is two millivolts per volt. The shaft mounts a 120 ohm full bridge strain gage. Solid silver slip rings and silver graphite brushes hold thermoelectric voltages below two microvolts, peak to peak, at full speed of 10,000 rpm. Dimensions are: length, excluding shaft extensions, 4¾"; width 3"; base-to-shaft height, 2¼". Lebow Associates, Detroit Michigan.

Circle No. 154 on Inquiry Card.

Stable Size 8 Synchro

New 400 cycle synchro control transformer has minimum error variations from −55C to +125C. It has stainless steel housing and all molded parts are made from special material with high impact strength, excellent dimensional stability, superior heat resistance and good electrical properties. Input voltage is 11.8V, input current 0.030 amps, input watts 0.073w, output voltage 22.5V, phase shift 8.5° (lead), rotor resistance 3.6 ohms, stator resistance 67 ohms, Z_{ro} 500 + J1937 ohms, Z_{so} 79 + j350 ohms, Z_{rss} 594 + j182 ohms, null voltage 30 mv and max. error from E.Z ± 7 minutes. John Oster Manufacturing Co., Racine, Wisconsin.

Circle No. 152 on Inquiry Card.

Transistorized Servo Indicator

Designed to operate where high input impedances are required, the Model 20-200-4 aircraft servo indicator, using silicon transistors, has an input impedance of 100,000 ohms to 1 megohm. Completely contained in a MS-33639 2 inch diameter by 5 inches long hermetically sealed case, the indicator will operate in an ambient temperature range of −55C to +70C. It has a sensitivity of 0.1%, a gain of 10,000 and a slewing time of approximately 4 seconds for full scale. Self-contained power supply operates on an input of 115 volts, 400 cycles. Includes a wide selection of dial configurations, a high speed vernier sub-dial, counters and integral lighting. Servo Development Corp., Westbury, L.I., N.Y.

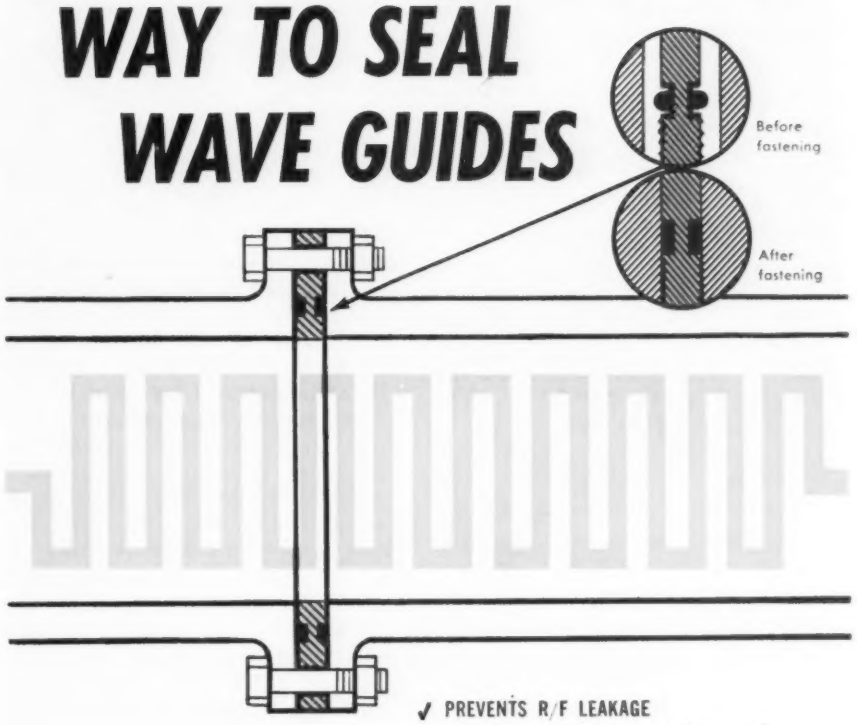
Circle No. 252 on Inquiry Card.

Tiny Rotary Switch

New rotary switch weighing less than 3 ounces and measuring only 1.5 inches long and 1.375 inches in diameter is said by the manufacturer to cut down the space formally required for ordinary relays by 80%. It can be used for stepping, counting, programming, circuit selecting and homing. A low-cost unit with built-in ability, meeting all applicable environmental tests of MIL-E-5272B, it can be either self-stepped or externally impulsed. It is actuated by a rotary solenoid and can hold up to four 12-position circuit wafers, with 2-, 3-, 4-, 6- or 12-electrical position selective control. Wire sizes are available to accommodate 3 to 300 volts D. C., 1,000 volts VRMS Hi-pot. Hermetically sealed models available. G. H. Leland, Inc., Dayton, Ohio.

Circle No. 251 on Inquiry Card.

NOW THERE IS A BETTER WAY TO SEAL WAVE GUIDES



✓ PREVENTS R/F LEAKAGE
Metal-to-metal contact with "engraved fingers" on inside surfaces assures electrical continuity.

✓ PROVIDES NO-LEAKAGE SEALING
Controlled confinement of seal gland assures safe, sure, positive sealing — **exceeds** top hermetic specs!

✓ ELMINATES ARCING AND/OR BURNING
Designed to exacting requirements for proper mating of flanges as specified.

✓ CAN BE RE-USED
Seal is never "squeezed" beyond elastic limits, "memory" is constant, before, during and after fastening.

✓ ECONOMICAL
Eliminates cleaning or resurfacing flanges, no intricate machining required to accommodate the seal, and they're resuseable with just normal care.

✓ STANDARDS FOR W/R SERIES
Electr-O-Seals are available as standards to WR series Wave Guide flanges, assuring adequate supply and economy.

In addition to the standard WR series wave guide flange seals, Parker Seal Company also makes special seals to meet almost any specification or configuration. A nation wide group of field engineers are available to aid in expediting your requirements.

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Parker SEAL COMPANY
Culver City, California and Cleveland, Ohio
A DIVISION OF PARKER-HANNIFIN CORPORATION

CIRCLE NO. 27 ON INQUIRY CARD

New Electronic Components For Electromechanical Systems

Low-Power Ten-Bit Magnetic Shift Register

Unit is available in several repetition rates from 10 KC to 400 KC. This compact module is complete with Shaper-Driver and mating connector. Output signal with a minimum of 25:1 One:Zero ratio. The low drive requirements permit a 100-milliampere shift pulse with only 5-volt peak drop across 200 bits. Two-hundred bits of register (20 cards) fit in a Standard DI/AN housing 3½" high in a standard relay rack. The register operates from one voltage with a ±15% tolerance. The SRA-10 family is available in six or twelve volts up to 100 KC and in 12 volts for the 250 and 400 KC units. Standby power is .06 watts for the ten stage register and driver. At rated repetition rate for all ONE's, the power consumption is 1.2 watts. Power consumption is proportional to the number of ONE's shifted per unit time. DI/AN Controls, Inc., Roxbury, Mass.

Circle No. 247 on Inquiry Card.

Random Noise Generator

An extremely versitile instrument, capable of generating wide-band noise of an uniform spectrum level, a random noise generator has many applications for electrical and mechanical testing. A gas-discharge tube is used as a noise source; a magnetic field, applied to the tube, serves to eliminate oscillations usually associated with a gas discharge. Noise output is amplified in a two-stage amplifier, which features noise-spectrum shaping filters controlled by a three-stage front-panel switch. The 20 kc setting introduces a low-pass filter providing a gradual roll-off above 30 kc, the 500 kc setting inserts a low-pass filter that rolls off above 500 kc, and in the 5 mc setting is a peaking network that compensates for the drop in noise output from the gas tube at high frequencies, so that a good spectrum can be obtained. General Radio Co., West Concord, Mass.

Circle No. 256 on Inquiry Card.

AC Voltage Regulator

Competely transistorized, a cool-running ac voltage regulator provides a miniature, frequency insensitive source in a plug-in package. This new component is intended to replace heavier, larger, rack-size sources that use magnetic amplifiers or frequency sensitive transformers. Operating at 55-65 cps., 105-125 vac input and providing regulation of ±1% half load to full load, three models are available with outputs of 115,6.3 and 12.6 vac at 1,10 and 5 amps respectively. Models meet the military requirements of MIL-E-582A. Electronic Assembly Co., Roxbury, Mass.

Circle No. 248 on Inquiry Card.

Choose From The Widest Variety Of Thermocouple Wires

Over 1500 Different Types

T-E's tremendous variety of thermocouple extension wires assures you quick delivery of every type and size—from one reliable source. Dependable quality control is also assured by T-E's own complete facilities for wire drawing, insulating and calibrating. T-E duplex wires come in solid or stranded construction, in all standard calibrations. The latest types of insulation and metallic armor overbraid protect them from all atmospheric, chemical and abrasive conditions. From 6 to 56 pairs of T-E thermocouple leads can now be installed at one time with the new "Thermo-Cable". Also available—a complete selection of "MIL"- Spec Wire.

See Our Full Line—

Write for Wire Bulletin 32WS-8

Thermo Electric CO., INC.
SADDLE BROOK, NEW JERSEY

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THERMO ELECTRIC (Canada) LTD.,
Brampton, Ont.

CIRCLE 10 ON INQUIRY CARD

WORTH BUYING

Electromechanical Switches

All you need to know about design selection and application of electromechanical switches are in this 24-page reprint of Components Digest 8, Parts I and II. Supply is limited. Fifty cents per copy. Check or money order must accompany order.

Write to: Reprint Editor
ELECTROMECHANICAL DESIGN
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Precision Spring Design

16 pages detailing the complete design procedure for precision compression and extension springs. 2 sample problems, 1 for precision compression and 1 for precision springs, worked out in detail on typical design procedure work sheets. 9 tables, 13 graphs, 3 nomographs, 4 detailed drawings, 2 worksheets.

Price: 50 cents each – 3 for $1.00 – 8 for $2.00. Check or money order must accompany request.

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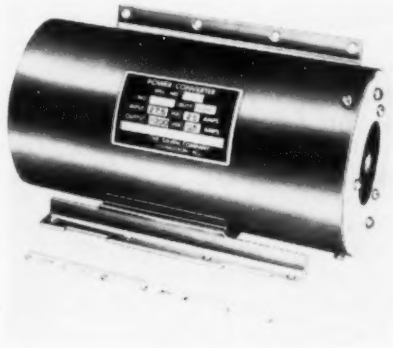
High-Power Silicon Rectifier

New series of light-weight high-power silicon rectifiers (Type-300) is now available in nine peak-inverse-voltage ratings from 50 to 500 volts. The hermetically-sealed cells can be used to provide up to 70 amperes of forward direct current. The high-current units weigh less than three ounces. Rugged construction, long life, high efficiency, good regulation and the ability to operate in high ambient temperatures—up to 190 degrees C junction—are features that allow the cells to be used in aircraft and missile or industrial applications. Maximum reverse current is 30 milliamperes at rated peak-inverse-voltage. The rectifier case is the positive (cathode) terminal and is nickel plated to maintain low contact resistance. A ⅜-inch threaded stud on the case permits mounting of the units in any position. The Type 300 cells are also available in complete bridge assemblies. Westinghouse Electric Corp., Pittsburgh, Pa.

Circle No. 205 on Inquiry Card

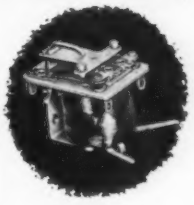


Transistorized Converters

DC to dc and dc to ac converters for the direct replacement of dynamotors in both military and commercial equipment eliminate the problem of brush replacement so common in equivalent rotating machines; they run for thousands of maintenance-free hours. They include a built-in AC blower which is entirely maintenance-free. Characteristics are: length 8-5/16″, diameter 4-1/8″ weight 7.75 pounds, input voltage 22.0 VDC to 30.0 VDC, input current less than 25 amperes, output voltage 1,000 VDC, output current 0.5 ampere, duty cycle continuous, operating temperature —55C to +85C under full load and continuous duty, ripple vo'tage less than 6.0 volts RMS. Regulation 14% maximum from zero to full load. The unit will withstand an over voltage to 34.0 VDC input for five minutes. It is efficiency rated for more than 2,500 hours of continuous duty. Daven Company, Livingston, N. J.

Circle No. 170 on Inquiry Card.

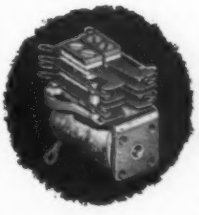
Cramped quarters don't cramp the style of ADVANCE midgets and miniatures. You can use them on loads from 1 to 10 amperes continuously ... and at three times their rating intermittently—with complete safety. They'll resist shock and vibration ... stand up under temperature extremes. You'll find them readily adaptable to any mounting need ... any type of duty. Some examples:



Miniature DC Type

MK SERIES

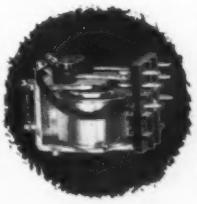
Extreme light weight and small size—requires only .5 cu. in. mounting space. Switching is above ground, insulation material is silicone glass. Beryllium copper armature hinges provide stability under shock and vibration.



Miniature Telephone Type

TQ SERIES

Only .94 cu. inches in size, yet this relay carries 3-amp. loads in any combination up to 6 PDT. Mechanically secured throughout, it's extremely efficient. Non-gassing insulation. Withstands 10G vibration. Temp. range: —50° to +85°C.



General Purpose Midget

GH SERIES

Engineered for high efficiency in thousands of applications. The small size of these midgets allows installation where space is a problem. Available in open types, 5- and 10-amp. ratings ... in dustite plastic enclosures, 5 amps., and 5-amp. plate circuit types.

AVAILABLE OFF THE SHELF

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CIRCLE NO. 43 ON INQUIRY CARD

put HEINZE in your designs

POWER

in compact size...

HEINZE UNIVERSAL MOTORS

When you want power in compact series motors, Heinze Universal Motors provide high starting torque, variable speed, reversibility and high output. Originally developed for sewing machines and office machines, they are extremely flexible in design for a variety of uses not requiring constant speed. Flat sided models are especially adaptable for limited space.

Horsepower ratings are from 1/10 to 1/30. Load speed is 7,500 rpm. Standard voltage rating is 115V, AC/DC but motors are supplied for other voltages in AC or DC. Rotation is CW, CCW, or reversing. Optional mounting arrangements include tapped holes on flat side.

Send coupon for new catalog on Heinze Universal Motors — plus the complete line of Heinze sub-fractional horsepower motors and blowers.

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CIRCLE NO. 32 ON INQUIRY CARD

New Mechanical Components For Electromechanical Systems

Limit Stop Assembly

Compact heavy duty limit stop Assembly available from stock and made to MIL specifications are available in both ball bearings and oil-less bronze bearings with a wide range of mechanical stop limits from 30 degrees to 4,530 degrees. The units are self-adjustable for fine "zero" adjustment. They are good for stopping torques up to 500 in. oz. Detailed information and prices are contained in new 416-page PIC Master Catalog #20a. PIC Design Corporation, East Rockaway, L.I., N.Y.

Circle No. 159 on Inquiry Card.

Pressure-Contact Terminal Blocks

A vise-like grip on each wire of through-connected pairs, eliminating soldering and providing extra safety against accidental shocks, characterizes the rugged pressure-contact terminal blocks designed for heavy-duty uses. Type 9-85 blocks are of one-piece construction, molded of general-purpose phenolic, or can be supplied in plastics as per MIL-M-14E. Top and bottom are closed with molded plastic so that no "live" metal is exposed. Wires are inserted from both sides of the block and a center bridge prevents wire leads from going all the way through. Wires can be disconnected from either side, while wires on opposite side remain connected. Each terminal position has two pressure-contact set-screws in conjunction with thick cross-section copper-bronze contact members, facilitating threading and assuring a good, deep, positive thread that cannot strip under normal torque. Kulka Electric Corp., Mt. Vernon, N. Y.

Circle No. 161 on Inquiry Card

Low Frequency Mounting System

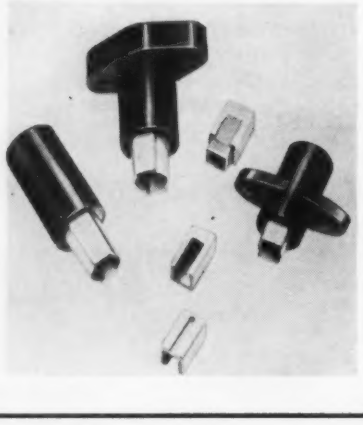
A dual suspension concept, combined with MET-L-Flex stainless steel, resilient cushions, results in all-metal mounting system which provides excellent protection above 10 cycles per second, a range which had previously resulted in damage to equipment. High inherent damping factors (15%-20% of critical) plus nonlinear spring rate of the cushions provide consistently high levels of equipment protection. The base unit supports the entire equipment, providing isolation in the three principal planes, while the stabilizer unit affords additional protection from horizontal forces, thereby assuring attenuation of shock and vibration forces from any direction. Robinson Technical Products, Teterboro, N.J.

Circle No. 148 on Inquiry Card

Packaged Precision Drive Units

Precision drive units are complete in themselves eliminating the need for separate drive components such as indicators, dials, knobs, gears, etc. Three types are available: type PDW-1 is a precision drive, worm gear type unit affording the highest degree of accuracy. The mechanism utilizes a 180-1 ratio which allows direct dial readings of 1 min. of arc; the DSD-2 dual speed drive unit is a precision gear reducer with accuracy of 6 min. of arc or better. Compact DSD-2 drives feature an inner dial for coarse positioning, an outer dial for fine positioning, plus in-line input and output shafts with no backlash; DSD-3, economical dual precision drive unit has accuracy of 12-, min. of arc. Technology Instr., Acton, Mass.

Circle No. 153 on Inquiry Card



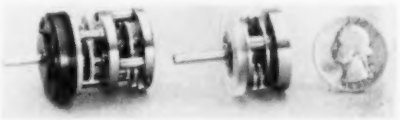
Brush Holder

A new captive holder for carbon brushes incorporates cap and holder with or without metal inserts, for a lower cost, one-piece assembly. This component is available in various sizes and types with optional insulating materials. Midwest Molding & Mfg. Co., Gurnee, Ill.

Circle No. 188 on Inquiry Card.

Servo-Motor Gearheads

Planetary gearheads are available with ratios up to 2500:1 with a torque rating of 25 oz. in. and maximum backlash of 10 minutes. The overall length of only 0.800″ is an important feature. Spur units are available with ratios up to 4000:1. In the low ratio series up to 37:1 two overall lengths are offered: 0.500″ for a torque rating of 25 oz. in.



and 0.609″ for a torque rating of 50 oz. in. The maximum backlash is 15 minutes. All units in the higher ratio series from 38:1 up to 4000:1 have a torque rating of 50 oz. in. and maximum backlash of 30 minutes. All gearheads are guaranteed for 2000 hours operating life and are available as complete units assembled to size 11 BuOrd servo-motors. U.S. Gear Corp., Wakefield, Mass.

Circle No. 179 on Inquiry Card.

High Temperature Ceramic Bushings

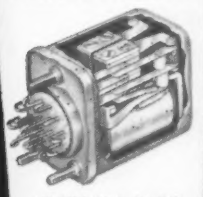
Ceramic bushings capable of withstanding 2000 deg.F. continuous operating temperatures, are now available in a wide range of sizes held to micro-thousandth tolerances. The bushings are available in diameters ranging from 12.00″ O.D. down to .028″. Standard tolerances are held to plus or minus ½%, and as close as plus or minus .0002″ both on diameter and wall thicknesses. Duramic Products, Inc., Palisades Park, N. J.

Circle No. 171 on Inquiry Card.

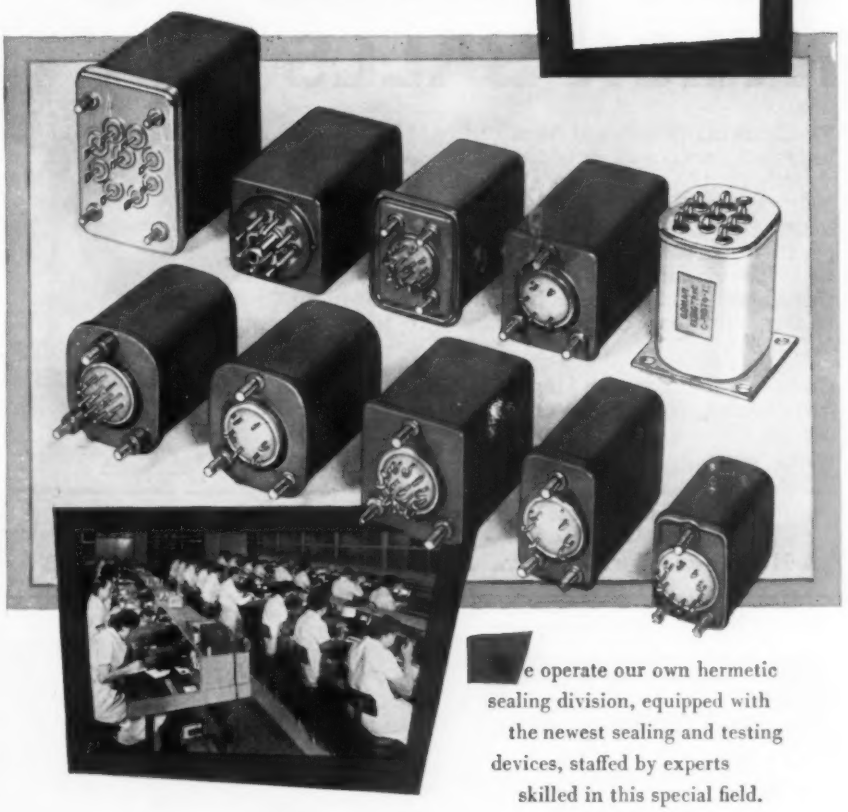
Comar saves you time and money on

hermetically sealed RELAYS

PRECISION ENGINEERED



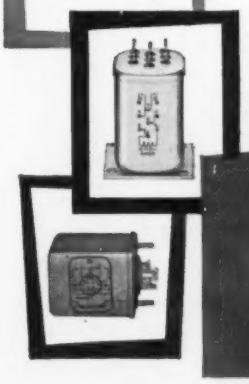
IN OUR OWN PLANT



We operate our own hermetic sealing division, equipped with the newest sealing and testing devices, staffed by experts skilled in this special field.

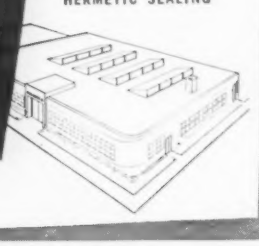
Complete facilities and know-how to produce dependable sealed relays for every requirement. Our engineers will custom-design a relay to meet your needs, or work from your own specifications. Save time and money . . . get your sealed relays from Comar. Prompt attention given to all inquiries. No obligation.
Comar Electric Co., 3349 Addison St., Chicago 18, Ill.

We also do our own plating and painting. Diagrams, etc., imprinted on enclosures.



Comar

RELAYS
SOLENOIDS
COILS
SWITCHES
HERMETIC SEALING



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CIRCLE NO. 38 ON INQUIRY CARD

FEB 29 1960

new way to make products better, more efficient...

ACE PRECISION NYLON BALLS

Precision manufactured from DuPont Nylon Resin to close tolerance of ±.001 on diameters and .001 on sphericity, Ace Nylon Balls give design flexibility and production economy. Light in weight... tough at low temperatures... stable at high temperatures... resistant to corroding chemicals such as sulphuric acid, etc.... almost abrasionproof... these mass-produced balls have hundreds of industrial applications. Come in 14 standard sizes from ⅛" to ¾".

Complete facilities for fabrication of plastic parts for all industries. Estimates submitted promptly on receipt of blueprints or specifications.

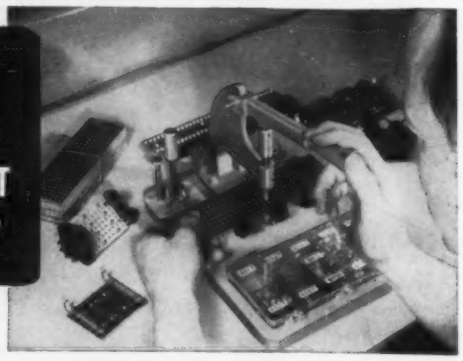
Write for Bulletin N, samples, price list, TODAY.

EXTRUSION MOLDERS AND FABRICATORS

ACE PLASTIC COMPANY
91-44 Van Wyck Expwy., Jamaica 35, N.Y. JAmaica 3-5500

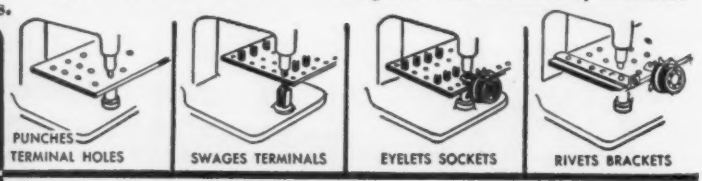
CIRCLE 65 ON INQUIRY CARD

NEW $49.95 KIT MOVES YOU FROM SCHEMATIC TO CIRCUIT *FAST & RELIABLY!*

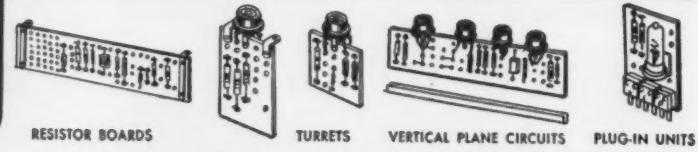


Here's an all-in-one tool for prototype and small production runs that makes it simple to organize and mount circuitry in compact, planes. It quickly swages Alden terminals, eyelets, brackets and tube sockets, and punches .101" terminal holes in Alden XXP phenolic cards or any 1/16" cold punch card. You can make up circuitry turrets in minutes — complete with terminals, brackets and sockets.

Does ALL these operations:



Makes ALL these parts:



SAVE $10 on kit over individual part prices. **Contains Alden Universal Staking Tool and assortment of prepunched terminal cards, terminals, tube sockets, brackets and eyelets to get started immediately. Order Kit #42 — $49.95 complete.**

ALDEN PRODUCTS COMPANY, 1138 North Main St., Brockton, Mass.

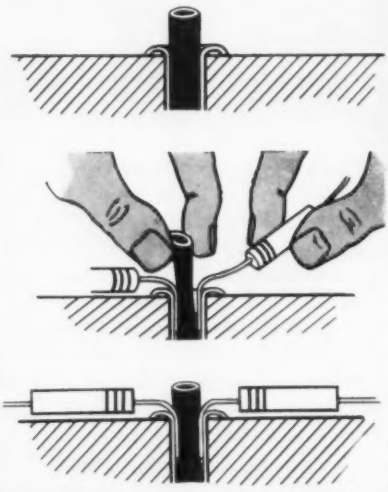
CIRCLE 5 ON INQUIRY CARD

MECHANICAL COMPONENTS

Lightweight Slip Clutch

A sub-miniature, adjustable slip clutch designed for devices requiring precision overload protection has a wide torque range of 0 to 100 in./ozs. with repeatable break-away torque. Other features include: no backlash, chatter, or galling; corrosion resistant materials; 0.630" dia. x 0.450" long; 0.03 lb. weight; concentricity to 0.0003". Northern Union, Inc., Arcadia, Cal.

Circle No. 191 on Inquiry Card.



A new method of providing fast, solderless connections between wires and component leads has been developed by engineers at Plastic Associates. A junction cell consists of a gold-plated eyelet and a long-wearing rubber core. When the core is pulled upward, the rubber stretches, allowing wires to be easily slipped inside the eyelet. When the rubber core is released, it grips the wires or component leads, pressing them firmly against the gold-plated surface and establishing an electrical contact of essentially zero resistance. Previous methods of providing fast, temporary connections of this type have generally depended on gripping the exposed wires between two opposing metal faces, as in the case of most clips, screw terminals and similar devices. This has caused trouble when the wires are of differing diameter since a larger wire "springs open" the holding device. The new junction cell solves this problem by gripping the wires between the metal surface of the eyelet and the soft, resilient rubber core which shapes itse'f around each wire, no matter what its size or shape. The rubber provides a firm gripping action that is essentially immune to vibration or shock. Plastic Associates, Laguna Beach, Cal.

Circle No. 127 on Inquiry Card

CIRCLE 7 ON INQUIRY CARD →